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BSM DELTA QUALIFICATION 2
FINAL REPORT

Volume I

11 November 1994

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UNITED TECHNOLOGIES CHEMICAL SYSTEMS

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BSM DELTA QUALIFICATION 2
FINAL REPORT

Volume I

11 November 1994

Submitted to:

USBI
Huntsville, AL

Prepared by

UNITED TECHNOLOGIES CHEMICAL SYSTEMS

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FOREWORD

This report, presented in three volumes, provides the results of a two-motor Delta Qualification 2 program conducted in 1993 to certify the following enhancements for incorporation into Booster Separation Motor (BSM) flight hardware:

- Vulcanized-in-place nozzle aft closure insulation
- New iso-static ATJ bulk graphite throat insert material
- Adhesive EA 9394 for bonding the nozzle throat, igniter grain rod/centering insert/igniter case
- Deletion of the igniter adapter insulator ring
- Deletion of the igniter adapter/igniter case interface RTV
- Deletion of Loctite from igniter retainer plate threads.

The enhancements above directly resulted from (1) the BSM Total Quality Management (TQM) Team initiatives to enhance the BSM producibility, and (2) the necessity to qualify new throat insert and adhesive systems to replace existing materials that will not be available.

Testing was completed at both the component and motor levels. Component testing was accomplished to screen candidate materials (e.g., throat materials, adhesive systems) and to optimize processes (e.g., aft closure insulator vulcanization approach) prior to their incorporation into the test motors. Motor testing — consisting of two motors, randomly selected by USBI's on-site quality personnel from production lot AAY, which were modified to accept the enhancements — were completed to provide the final qualification of the enhancements for incorporation into flight hardware.

This report addresses the motor level test results with summary discussions of the component level testing where appropriate. Volume I discusses the results obtained from the Delta Qualification 2 testing. Volume II details the environmental testing (vibration and shock) conducted at Marshall Space Flight Center (MSFC) to which the motors were subjected prior to static testing. Volume III provides various supporting documentation to Volumes I and II, including the analyses and plans that governed the testing of the two Delta Qualification units.

Section 1
INTRODUCTION

The Shuttle Booster Separation Motor (BSM) has been proven to be a very robust design. Not only has the BSM demonstrated a 100% flight success rate, but following the post-Challenger component reviews, the BSM was subjected to a thorough series of controlled overtests, including static testing of 11-year old motors (see references 1–7), which further verified the design robustness.

With the continued success of the BSM, the BSM TQM team has put forward several Total Quality Management/Continuous Improvement (TQM/CI) initiatives for enhancing the BSM producibility. Some of these initiatives involved enhanced production and inspection methods which did not directly impact the BSM design and which were readily implemented. These initiatives alone are estimated to provide a cost reduction of approximately 12% for BSM.

Additional enhancements have been identified which could further streamline the BSM production process. These enhancements, however, impact the BSM design and involve either material or process changes. Specifically, these TQM/CI enhancements are:

- **Process Changes**
  (1) Vulcanize the insulation to the nozzle closure instead of secondarily bonding the insulation. This improves the bond strength, provides total bondline contact, eliminates the closure insulation re-work which has occurred with the secondarily bonded approach, and potentially eliminates the need for NDT of this interface.
  (2) Delete the use of the silica-filled NBR insulator ring on the aft face of the igniter adapter due to the relatively low heat flux and large heat sink present in this forward dome area for the short motor action time.
  (3) Delete the use of an RTV protective bead at the igniter case-to-igniter adapter thread interface due to the relatively low heat flux present in this forward dome area.
  (4) Delete the Loctite adhesive on the igniter booster charge retainer plate threads due to the capture design feature of the igniter adapter and the igniter case.

- **Material Changes**
  (1) Qualifying a new adhesive (EA-9394 epoxy) in conjunction with environmentally friendly cleaning agents for bonding the nozzle throat insert into the nozzle closure due to future unavailability of the present EA-913NA/L-3 epoxy adhesive.
  (2) Replace the present slurry-molded bulk graphite ATJ nozzle throat material with an isostatic molded bulk graphite ATJ due to the vendor discontinuance of the slurry-molded material.
  (3) Bond the igniter centering insert into the igniter case and the igniter grain rod into the igniter centering insert with a new adhesive (EA-9394 epoxy) using environmentally friendly cleaning agents due to the future unavailability of the present EA-913NA/L-3 epoxy adhesive.

In order to introduce these enhancements into future Shuttle Transportation System (STS) flights, qualification of these enhancements through a series of component and motor environmental and static tests was completed. This test effort, designated Delta Qualification 2, culminated in the testing of two, randomly selected BSMs (one forward and one aft motor) from production lot AAY. These two motors incorporated the previously mentioned design/enhancement changes.

The Delta Qualification 2 motors were subjected to environmental conditions compliant with the 10SPC-0067 specification requirements as modified by USBI direction and subsequently static tested under temperature conditions which were outside of the specification limits. This latter requirement effectively provided an overtest of the enhancements in a motor environment and provided additional confidence in their acceptability for incorporation into future STS missions.

All tests were successfully completed. The tests were performed to verify, item by item, that the design enhancements/changes would support motor function to all of the 10SPC-0067 requirements.

This report documents the results of the two Delta Qualification environmental and static tests. The results reported herein provide the basis for the qualification of and the recommendations for incorporation of the BSM enhancements identified above into STS flight hardware.

Section 2 of this report presents a summary of the verifications performed to justify the Certification of Qualification (COQ) of the proposed configuration according to the requirements of 10SPC-0067A. Verifications were accomplished by means of similarity, analysis, inspection, demonstration and test. Included in Section 2 is the BSM certification matrix, which provides a complete summary report on the formal demonstration of conformance to the BSM certification requirements.

BSM certification requirements were specified to include various test demonstrations which constitute a significant portion of the verifications summarized in Section 2.

Section 3 contains detailed descriptions of the test motor configurations and conditions which provided certification test data. Section 4 presents the description and summary of the environmental tests, the details of which are provided in Volume II.

Section 5 presents the results of the motor static tests and evaluates their performance against the motor performance requirements of the 10SPC-0067 specification. Motor performance compliance with the specification is mandatory for a valid enhancement qualification.

Section 6 presents an evaluation of each of the enhancements as well as of the overall motor and of the sealing O-rings. The enhancement discussions address each TQM initiative under investigation, the success criteria against which the performance of each enhancement was judged, the test results for each enhancement, the conclusions based on the test results/sucess criteria and the recommendation for each enhancement.

Section 7 provides the top level summary of conclusions and recommendations resulting from this Delta Qualification effort.

Volume II presents the test report published by MSFC documenting the environmental testing of the two Delta-Qualification motors at their facility in Huntsville, Alabama.

Volume III presents a series of appendicies which provide additional supporting documentation for the efforts discussed in Volumes I and II.

Based on the results of the tests reported herein, all of the design/enhancement changes included in the Delta Qualification motors are recommended for incorporation in BSM flight hardware.

Section 2
DELTA QUALIFICATION 2 SUMMARY

The Delta Qualification 2 testing program has been successfully completed in accordance with the requirements of BSM End Item Specification 10SPC-0067A, Table VII. The BSM configurations involved in the Delta Qualification 2 activities are listed in figure 2-1.

BSM P/N	Motor S/N	Nozzle S/N	Igniter S/N	Case S/N
B12000-13-01*	1000738	WO442	5569	IO511
B12000-14-01†	1000734	IO705	5568	IO705

*Forward motor
†Aft motor

Figure 2-1. Motor Component Identification

Demonstration of compliance with specification requirements was accomplished by a combination of five verification methods: (1) similarity, (2) analysis, (3) inspection, (4) demonstration and (5) test. These methods are defined as follows:

Similarity. The enhancements identified above were considered to be improvements over the existing design. In all cases, the enhancements were similar to the existing design. Therefore, where appropriate, comparison of the enhancements performance with that of the original design was used in combination with one or more of the following methods to further validate the acceptability of the specific enhancement.

Analysis. Verification by analysis was accomplished by an analytical evaluation of the enhancement or by an analytical comparison between the enhancement and the original design which had been previously verified.

Inspection. Verification by inspection was accomplished by measurements and visual observations indicating that the motor hardware involved in the certification program conformed to drawings and specifications which had previously been prepared in accordance with the design configuration to be certified.

Demonstration. Prior to incorporation into a motor for verification by test, selected enhancements were subjected to demonstrations through the use of standard test specimens (e.g., adhesive screening) or component hardware which conformed to the proper configurations (e.g., aft closure vulcanized insulator) for the purpose of either obtaining an extended database (e.g., impact of external environments such as fog, salt, etc.) for enhancing or optimizing the process (e.g., vulcanized insulator) prior to test.

Test. Verification by test was accomplished by testing hardware in two BSMs that were subjected to motor level environments, recording the results of the test and comparing those results to the

10SPC-0067 performance requirements. The scope of this activity also includes the Engineering analysis of the test data to demonstrate compliance to the 10SPC-0067 specification. The results of these analyses are reported in Section 4.

Figure 2-2 provides a cross reference between the Delta Qualification enhancements and the verification methods described above. Figure 2-3 provides a compliance matrix between the requirements of Specification 10SPC-0067 and the Delta Qualification test results.

The applicable test plans used in governing the Delta Qualification testing are as follows:

- Delta Qualification Test Plan, CSD 5597-93-1, Rev. B
- Mix Acceptance Motor Test, CSD Specification No. SE 0837, as modified by USBI direction

Copies of these documents are included as Appendices D and E, respectively, in Volume III of this report.

All essential BSM requirements for controlling the manufacturing, processing and testing operations for the two BSM Delta Qualification motors were verified and documented by CSD's Quality Assurance department. In addition, all Air Force mandatory inspection points identified by NASA were verified by the local Government/QA group. These documented verifications are recorded in CSD manufacturing books which are on file in the QA data center.

A total of 18 non-conformance reports (NCRs) were processed in connection with the two Delta Qualification 2 motors. A summary listing of the NCRs showing their applicability to each motor is shown in Section 3.1 with copies of the NCRs provided in Appendix J of Volume III.

Enhancement Description	Verification Method				
	Similarity	Analysis	Inspection	Demonstration	Test
Vulcanized aft closure insulator	X		X	X	X
Delete igniter adapter insulator		X	X		X
Delete igniter adapter RTV bead			X		X
Delete Loctite on igniter booster charge retainer plate			X		X
Qualify EA-9394 for throat insert bondng	X			X	X
Qualify EA-9394 for igniter component bonding	X			X	X
Qualify iso-molded ATJ for throat insert	X	X	X	X	X

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Figure 2-2. Enhancement vs Verification Method

Performance/ Design 10SPC-0067A	Certification Requirement	Certification Method/ Source	Certification Results
3.2.1 BSM Performance			
3.2.1.1 Propulsion	Ballistic performance as specified in paragraph 3.2.1 over bulk temperature range of +25 to +125°F	Test two Delta Qualification 2 motors	Performance met all specification requirements (see section 5, and subsections 6.1 and 6.2)
3.2.1.2.1 Debris Protection	No debris shall be generated	Test two Delta Qualification 2 motors	High-speed film and posttest inspections showed no debris generated (see subsection 6.3.3)
3.2.1.2.3.1 Nozzle Operational Loads	Preclude debris and withstand operational loads	Test two Delta Qualification 2 motors	Sustained environmental tests (see Volume II) and static tests (see section 5); high-speed film showed no debris (see subsection 6.3.3)
3.2.1.2.3.2 Igniter Assembly	Preclude hot gas leakage	Test two Delta Qualification 2 motors	Sustained static tests (see section 5); posttest inspection showed no hot gas leakage (see subsections 6.1, 6.2, 6.4, 6.5, 6.6)
3.2.1.2.3.2.1 Igniter	Preclude debris generation	Test two Delta Qualification 2 motors	Sustained static tests (see section 5); posttest inspection showed no debris (see subsections 6.4 through 6.6)
3.2.1.2.3.7 Insulation Thickness Factor-of-Safety	Ensure posttest thickness meets 1.25 factor-of-safety	Test two Delta Qualification 2 motors; measure thicknesses	Posttest thicknesses show minimim factor-of-safety of 1.33 (see subsection 6.3)
3.2.1.2.3.9 Maximum Case External Temperature	Verify maximum case external temperature is less than 290°F during soakout	Test two Delta Qualification 2 motors	Temperatures were less than 290°F (see subsection 6.1)
3.2.1.2.3.12 Cork Bonding	Tensile bond strengths 50 psi	Porta-pull tests after case painting	Porta-pull tests on aft case successful (see subsection 6.1)
3.2.5.2 On-pad Stay Time	Performance to all requirements after exposure to natural and induced environments	Environmental and static testing two Delta Qualification 2 motors	Performance of both motors met all specification requirements (see Volume II and section 5)
3.2.7.2.2.1 Flight Vibration and Shock	Performance to all requirements after exposure to environments from liftoff and boost phases	Environmental and static testing two Delta Qualification 2 motors	Performance of both motors met all specification requirements (see Volume II and section 5)
3.3.6.9 Strength and Stiffness	Adequate strength and stiffness for all environments	Thermostructural analyses and environmental/static testing two Delta Qualification 2 motors	All margins of safety were positive for design changes (see Volume III)

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Figure 2-3. Delta Qualification Test Results Compliance with Specification 10SPC-0067 Requirements

Section 3
TEST CONFIGURATIONS AND CONDITIONS

This section addresses the motor test configurations and test conditions to which the Delta Qualification 2 motors were subjected. Specific discussion of the environmental and static test description and results are presented in Sections 4 and 5, respectively. Section 6 presents results of posttest examinations.

3.1 TEST CONFIGURATIONS. The enhancements noted in figure 3.1-1 are the changes to the BSM that have been validated by the adhesive qualification test program and the vulcanization test program for certification through the Delta Qualification 2 testing program. Figures 3.1-2 through 3.1-5 identify the configurations of the forward and aft motors and motor system components which were tested to provide the data used to establish qualification of the modified BSM. Figure 3.1-2 shows the forward motor assembly and figure 3.1-3 shows the aft motor. Both motor configurations were subjected to thermal cycling at CSD, vibration and shock testing at MSFC, and static testing at CSD as described in subsequent sections of this report. Each motor was subjected to the environmental shock and vibration testing with an aeroheat shield attached to simulate the nozzle exit cone mass distribution experienced in an actual SRB functioning. Figure 3.1-4 provides a detailed description of the forward/aft motor igniter adapter area design change/enhancements incorporated into these two motors. Figure 3.1-5 provides a detailed description of the motor aft end design change enhancements.

Process Changes	Material Changes
• Vulcanize insulation to the nozzle closure instead of secondarily bonding the insulation to improve bond strength, provide total bondline contact, eliminate closure insulation re-work which has occurred with the secondarily bonded approach, and potentially eliminate the need for NDT of this interface	• Qualify new, environmentally friendly adhesive (EA-9394 epoxy) for bonding the nozzle throat insert into the nozzle closure due to future unavailability of the present EA-913NA epoxy adhesive
• Delete use of the silica-filled NBR insulator ring on the aft face of the igniter adapter due to the relatively low heat flux present in this forward dome area	• Replace present slurry-molded bulk graphite ATJ nozzle throat material with an iso-static molded bulk graphite ATJ due to the vendor discontinuance of the slurry-molded material
• Delete use of an RTV protective bead at igniter case-to-igniter adapter thread interface due to the relatively low heat flux present in this forward dome area	• Bond igniter centering insert into igniter case and igniter grain rod into igniter centering insert with new adhesive (EA-9394 epoxy) due to the future unavailability of the present EA-913NA epoxy adhesive
• Delete Loctite adhesive on the igniter booster charge retainer plate threads due to the capture design feature of the igniter adapter and the igniter case	

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Figure 3-1.1. BSM Design Changes/Enhancements

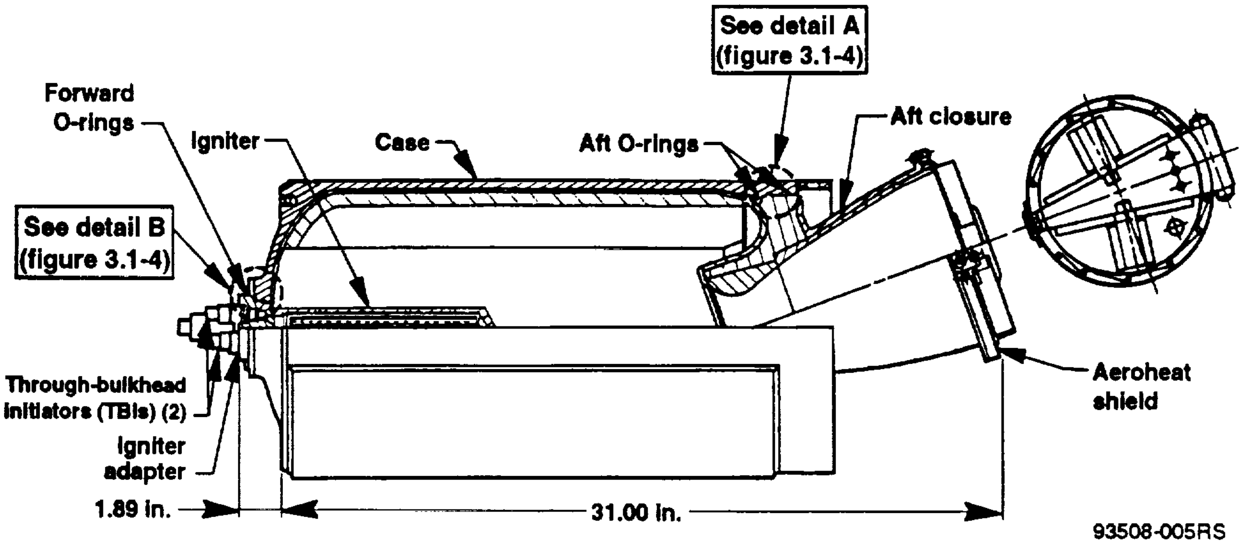

Figure 3.1-2. BSM Forward Motor Configuration with Aeroheat Shield

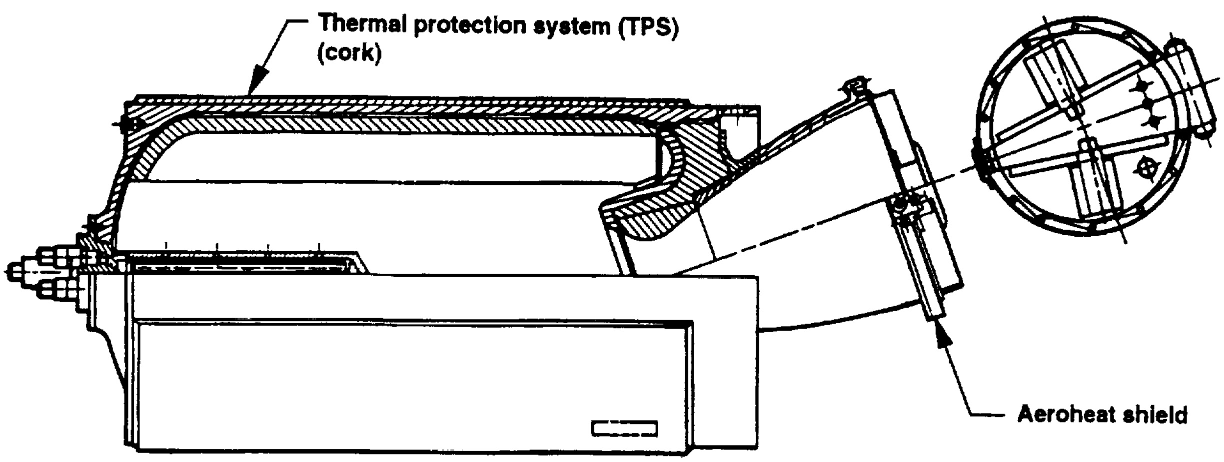

Figure 3.1-3. BSM Aft Motor Configuration with Aeroheat Shield

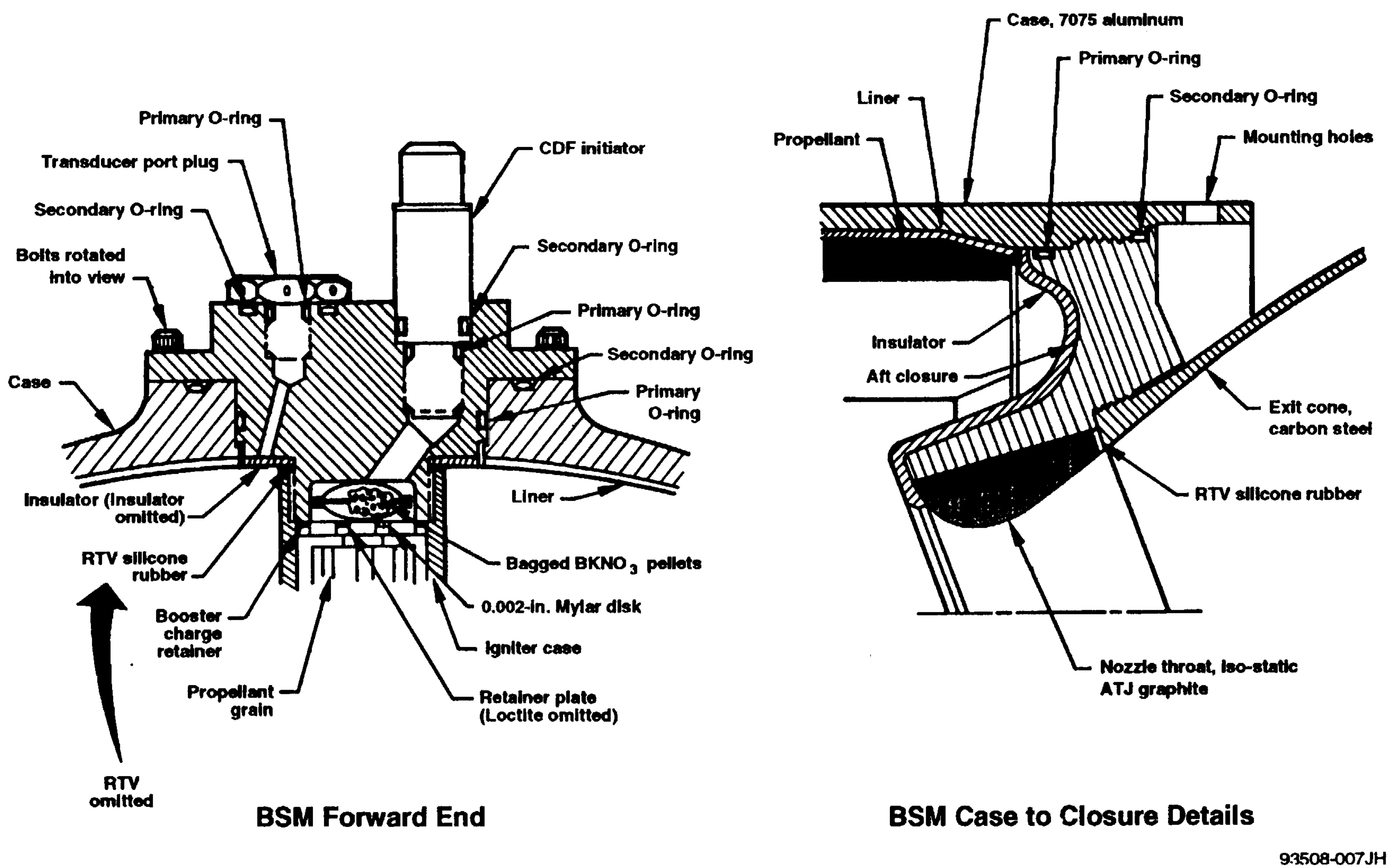

Figure 3.1-4. BSM No RTV Configuration

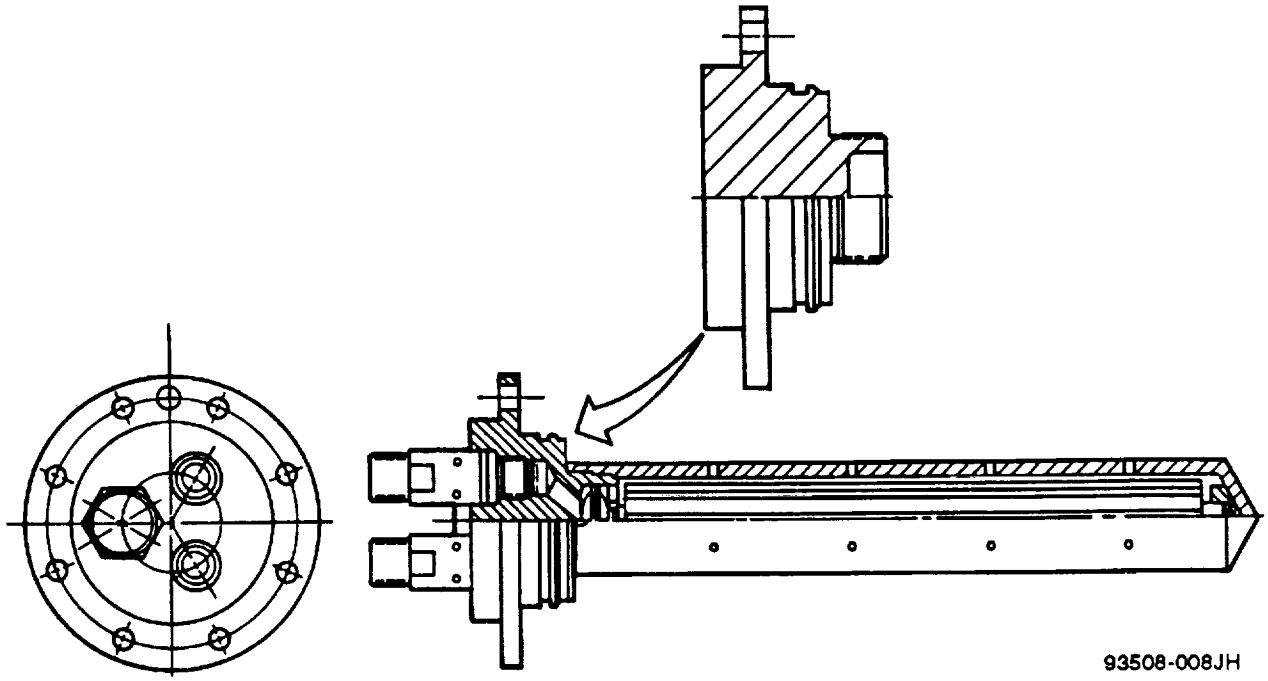

Figure 3.1-5. BSM Igniter Disassembly

The nonconformance reports (NCRs) against each motor are listed in figure 3.1-6.

3.2 TEST CONDITIONS. The various test conditions under which the motor and components of subsection 3.1 were tested are described in this subsection. The configurations identified in figure 2-1 were tested according to the controlling drawing or specification as referenced in the test matrix of figure 3.2-1. Figure 3.2-1 is a matrix description of the environmental test, static test and physical test conditions. The sequence in which each motor was subjected to various environmental conditioning/testing and static testing is identified by the numerical sequence listing for each motor.

All environmental testing of Delta Qualification 2 motors, other than temperature cycling and prefire temperature conditioning static firing, was performed at the Marshall Space Flight Center (MSFC).

Nomenclature	Part No.	Serial No.	NCR	Comments
A. Motor S/N 1000734				
Motor assembly, final	B12000-14-01	1000734	D12181	
Motor case, loaded	B12002-02-01	10705	D10909	
Case/aft closure	B12018-02-01	10705	B13616	(Superseded by B19943)
Case/aft closure	B12018-02-01	10705	B19943	
Adapter, igniter	B12016-02-02	5568	D05044	
Nozzle assembly	B12003-10-01	I0705	D11910	VMRR 006184
Nozzle assembly	B12003-10-01	I0705	D11923	
Nozzle assembly	B12003-10-01	I0705	D12186	
Nozzle assembly	B12018-14-01	I0705	D10070	
Closure, aft	B12003-09-01	I0705	D14417	
Anti-oxidant	SE0724	Lot 20, all motors	D08388	
HX-752	SE0754	Lot 50, all motors	D08262	
Motor assembly	B12000-14-01-501	1000734	D12394	
B. Motor S/N 1000738				
Motor case, loaded	B12002-02-01	1000738	D10909	
Case/aft closure	B12018-02-01	I0511	B13616	(Superseded by B19943)
Case/aft closure	B12018-02-01	I0511	B19943	
Adapter, igniter	B12016-02-02	5569	D05044	VMRR 006185
Nozzle assembly	B12003-09-01	W0442	D11927	VMRR 006186
Nozzle assembly	B12003-09-01	W0442	D11959	
Nozzle assembly	B12003-09-01	W0442	D10275	
Closure, aft	B12018-14-01	W0442	D14416	
Anti-oxidant	SE0724	Lot 20, all motors	D08388	
HX-752	SE0754	Lot 50, all motors	D08262	
Motor assembly	B12000-13-01-501	1000738	D12391	

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Figure 3-1.6. NCR Summary

Test Environment	Forward	Aft
BSM P/N Serial numbers	B12000-13-01 1000738	B12000-14-01 1000734
Temperature cycling*	1	1
Liftoff vibration†	2	2
Boost vibration†	2	2
Vehicle dynamics vibration†	2	2
Vibration conditioning temperature	125+5/–0°F	25+0/–5°F
Ordnance shock (ambient)†		
Prestatic test X-ray*	3	3
Motor test at specified temperature (reference SE0837)*	4 (130+5/–0°F)	4 (20+0/–5°F)
Closure UT/tap test*	6	6

* Conducted by CSD
† Conducted by MSFC (Marshall Space Flight Center)
Note: Liftoff, boost, and vehicle dynamics vibration may be performed in any sequence to save time and cost, and the motor S/Ns specified will be conditioned at the temperature shown. Numbers listed below each motor indicate sequence of test environments.

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Figure 3.2-1. BSM Delta Qualification 2 Motor Test Matrix

Section 4
ENVIRONMENTAL TESTING DESCRIPTION

In order to qualify the BSM enhancements for incorporation into flight hardware, the two Delta Qualification 2 motors were subjected to environmental and static tests as summarized in figure 3.2-1. This section summarizes the results of the pre-static test environmental testing with detailed results presented in Volumes II and III.

Appendices A and B in Volume III provide the planning acceptance records with respect to the details of the environmental testing.

Section 5 addresses the results of the static tests.

4.1 INERT MOTOR VIBRATION TESTING. Prior to conducting the Delta Qualification 2 environmental tests, an inert motor with components bonded with the new EA 9394 adhesive was tested by MSFC at the Huntsville, Alabama facility to the same vibration and shock environments as in the test plan for Delta Qualification 2 motors. This testing was done as a precursor to testing the final assembled Delta Qualification 2 motors.

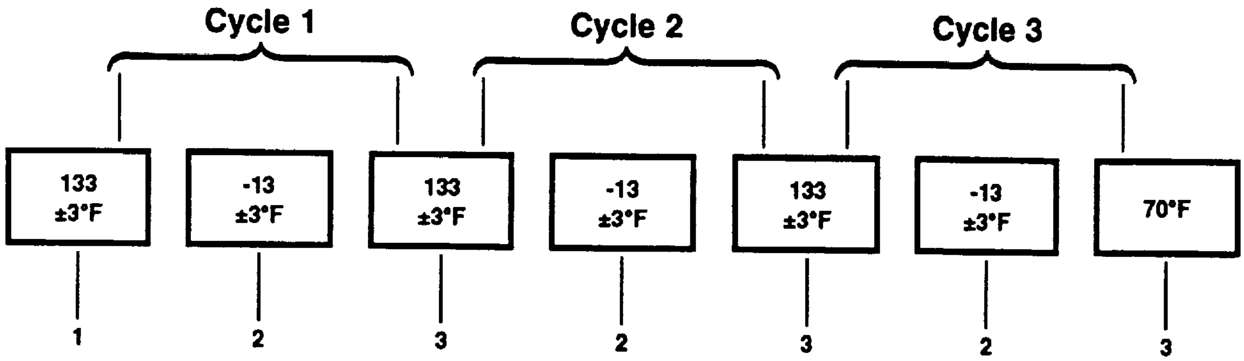
This test was an extension of the EA-9394 adhesive laboratory tests (see subsection 6.7 in this volume and Appendix H in Volume III). The purpose of this test was to verify that, after the adhesive EA 9394 had been chosen by qualification lab tests, the assembly bonds would survive the actual SRB/ASRM launch/boost/vehicle dynamic shock and vibration environments before testing live motors.

4.2 TEMPERATURE CYCLING. The initial environmental test to which both Delta Qualification 2 motors were subjected was temperature cycling. Each motor was temperature cycled at CSD through three continuous cycles as shown in figure 4.2-1. Each temperature cycle consisted of stabilizing the motor at 133±3°F for 24 hr, transferring within 5 min to a cold chamber until stabilized at −13±3°F for 24 hr and then within 5 min returning the motor to the hot chamber and stabilizing again at 133±3°F for 24 hr for the start of the next cycle. At the end of the third cold conditioning cycle, the motors were allowed to recover to ambient temperature (approximately 70°F). The total temperature cycling time for the motors was 7 days.

Both motors were successfully subjected to the required temperature cycles as verified by the recorded temperature histories provided in Appendix A in Volume III.

4.3 VIBRATION AND ORDNANCE SHOCK TESTS. Following temperature cycling, both motors were shipped to MSFC for vibration testing at temperature extremes and shock testing at ambient temperature (see Volume II).

The motors were subjected to combined forward/aft/SRB/ASRM vibration tests as specified to CSD by USBI and described in figures 4.3-1 through 4.3-3 and in the test plan provided in Appendix C of Volume III. Compliance with these test requirements is presented in Volume II and Appendix B in Volume III.



Procedure

(1) Hold the motors at a stabilized average air temperature of 133±3°F for 24 hr minimum.

(2) Subject the motors -13±3°F within 5 min of removal from the 133°F conditioning. Hold the motors at a stabilized average air temperature of -13±3°F for 24 hr minimum.

(3) Subject motors 133±3°F within 5 min of removal from the -13°F conditioning. Hold the motors at a stabilized average air temperature of 133±3°F for 24 hr minimum.

(4) After repeating steps (2) and (3) two more times (a total of three cycles), allow the motors to recover to ambient temperature (approximately 70°F) prior to further processing.

The total temperature cycling period is approximately 7 days.

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Figure 4.2-1. Delta Qualification Motor Temperature Cycling

Radial Axis				
		20 Hz at	0.017	g2/Hz
20	to	55 Hz at	+6	dB/oct
55	to	200 Hz at	0.077	g2/Hz
200	to	280 Hz at	–11	dB/oct
280	to	1200 Hz at	0.022	g2/Hz
1200	to	2000 Hz at	–4.5	dB/oct
	to	2000 Hz at	0.010	g2/Hz
Composite = 6.9 grms				
Longitudinal and Tangential Axes				
		20 Hz at	0.016	g2/Hz
20	to	75 Hz at	+3	dB/oct
75	to	1000 Hz at	0.060	g2/Hz
1000	to	2000 Hz at	–3	dB/oct
		2000 Hz at	0.030	g2/Hz
Composite = 10.0 grms				

93508-012

Figure 4.3-1. Liftoff Random Vibration Criteria — 60 sec/axis

Radial Axis				
20	to	200 Hz at	0.54	g2/Hz
200	to	350 Hz at	–12	dB/oct
350	to	1000 Hz at	0.060	g2/Hz
1000	to	2000 Hz at	–6	dB/oct
	to	2000 Hz at	0.015	g2/Hz
Composite = 14.0 grms				
Longitudinal and Tangential Axes				
20	to	800 Hz at	0.24	g2/Hz
800	to	2000 Hz at	–4	dB/oct
		2000 Hz at	0.071	g2/Hz
Composite = 18.4 grms				

93508-013

Figure 4.3-2. Boost Random Vibration Criteria — 120 sec/axis

Radial Axis			
2	to	5 Hz at	2.0 g peak*
5	to	10 Hz at	0.7 g peak*
10	to	40 Hz at	3.7 g peak*
Longitudinal and Tangential Axes			
2	to	5 Hz at	4.3 g peak*
5	to	10 Hz at	0.7 g peak*
10	to	40 Hz at	4.3 g peak*
*Design criteria only			

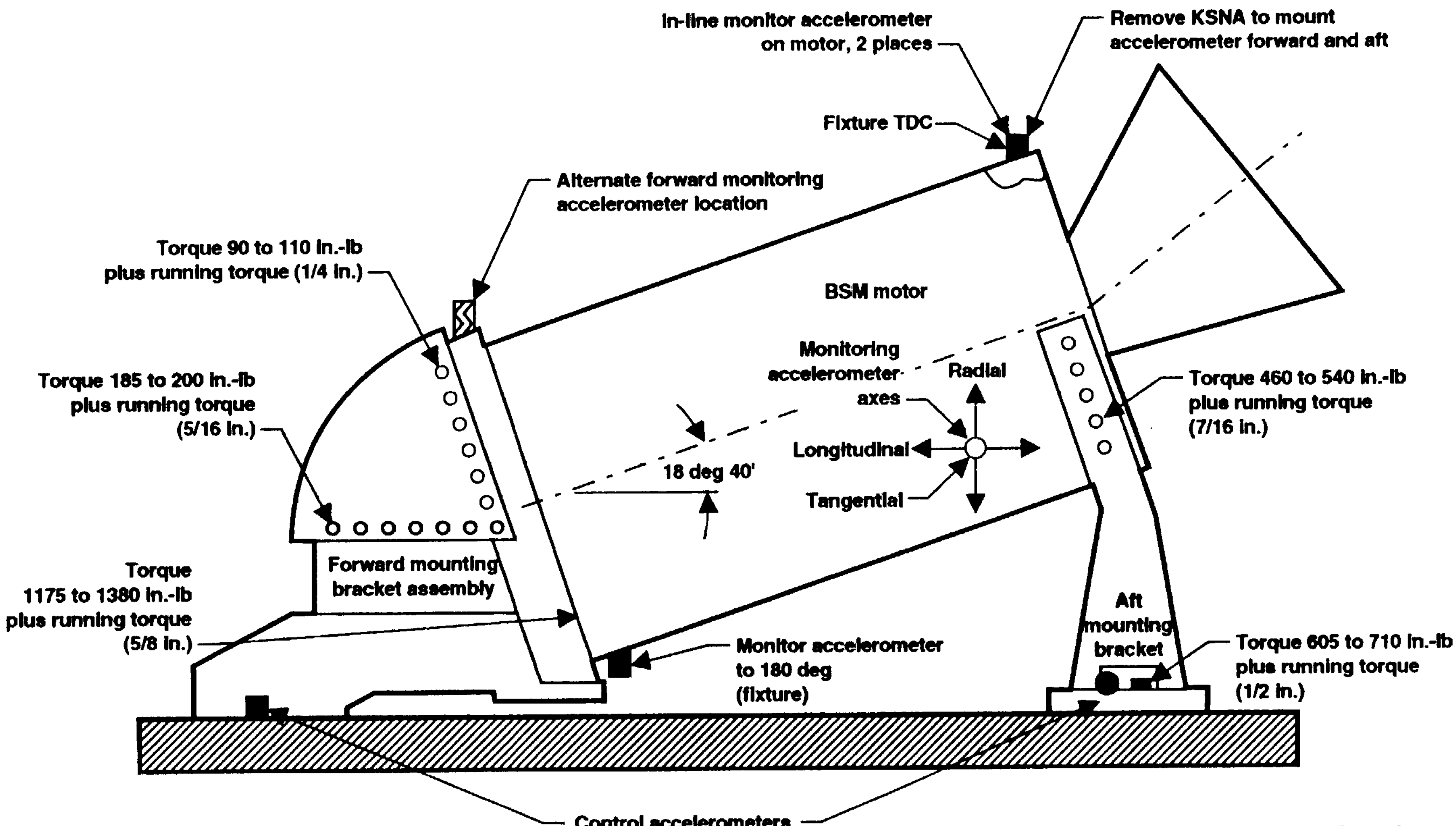
93508-014

Figure 4.3-3. Vehicle Dynamics Criteria — 3 octave/min Sweep Rate

The test fixture and arrangement of instrumentation for the motor vibration tests is shown in figure 4.3-4 for the radial, tangential and long-itudinal test axes. Testing in the longitudinal and tangential axes was accomplished by rotating the motor/attach brackets 90° on a slip table oriented parallel to the driver motor axis (see Volume II). To accomplish radial axis testing, the motor was placed on a horizontal table that was perpendicular to the driver motor axis (see Volume II).

The two Delta Qualification 2 motors were subjected to ordnance shock tests as defined in figure 4.3-5 at ambient temperature. The SRB aft motor thrust mount was used for motor mounting. The fixture, with motor installed, was mounted sideways on a vertical plate as shown in figure 4.3-6. Shock levels per figure 4.3-1 were achieved by control of the location and length of detonation cord attached to the backside of the plate to which the mounted BSM motor was attached.

Volume II provides the detailed results of the environmental testing conducted at MSFC and summarized above. Section 5 addresses the results of the static tests which were completed following return of the loaded motors to CSD from MSFC.



Note:

(1) If forward monitoring accelerometer cannot be mounted to the bracket assembly at fixture 180 deg location, it mat be mounted on the bracket at fixture TDC (forward)

(2) Monitor accelerometers to be aligned with vibration axes as shown

Drawn by:
K. Mitchell/EP 54
4/14/93

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Figure 4.3-4. Vibration Test Setup

Ordnance Shock Response Spectrum (Q = 10)			
		50 Hz at	24 g peak
50	to	100 Hz at	+12 dB/oct
		100 Hz at	94 g peak
100	to	4000 Hz at	+6 dB/oct
4000	to	10000 Hz at	3750 g peak
Shock spectrum tolerance: ±6 dB			

93508-016

Figure 4.3-5. Shock Test Criteria

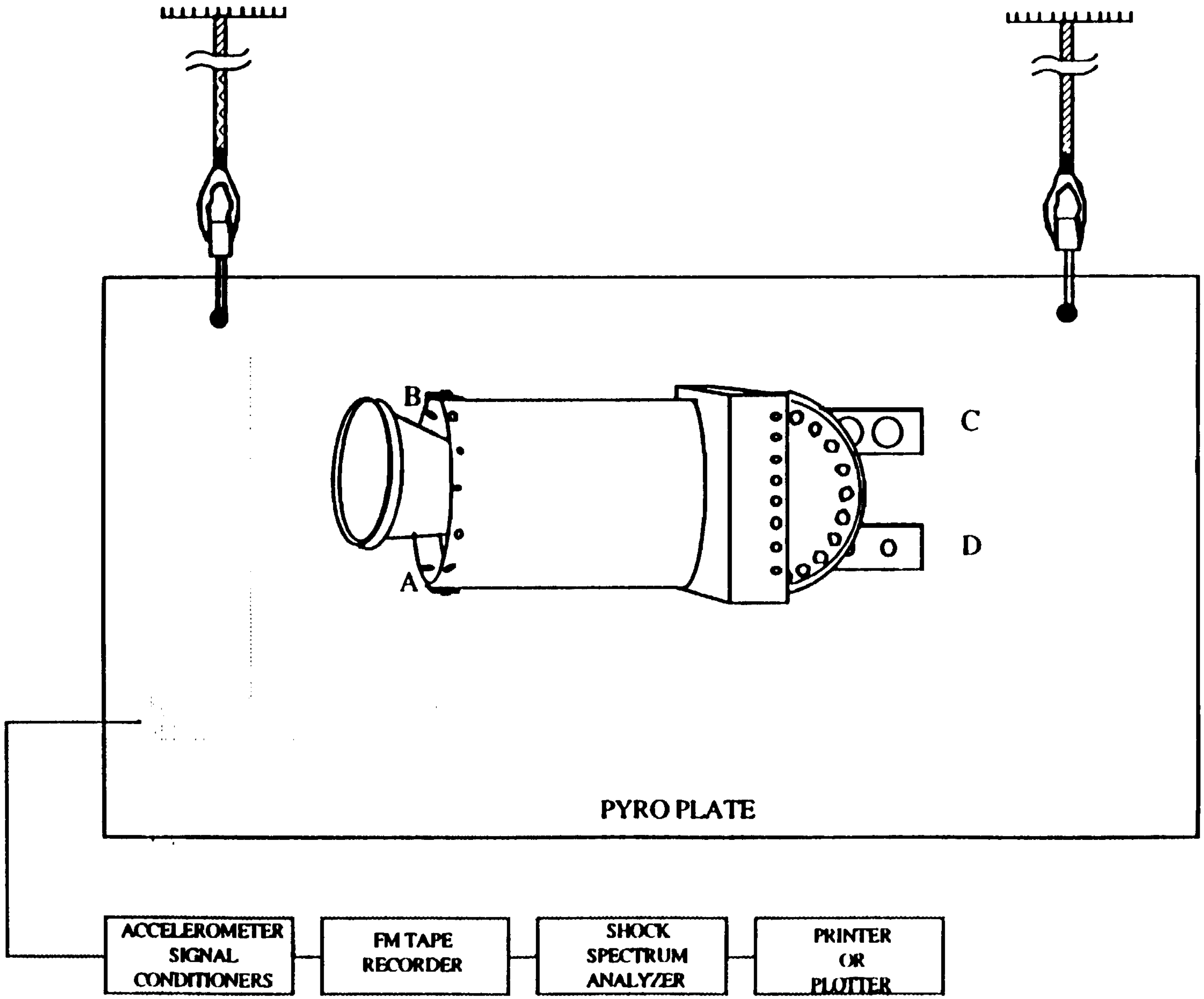


Figure 4.3-6. Pyroshock Control Equipment

Section 5
DELTA QUALIFICATION MOTOR STATIC TEST RESULTS

Following completion of the environmental tests at MSFC described in Section 4, the two BSMs from production Lot AAY, which incorporated the enhancements identified in Section 1, were returned to CSD for static testing.

Appendices D and E in Volume III provide the detailed test procedures and planning for the static testing of the motors. The results of the static tests are reported in this section.

Both static firing tests in the BSM Delta Qualification 2 program were conducted in test bay ST-3 at the CSD Coyote Facility in San Jose, CA using the six-component test stand illustrated in figure 5-1.

Motor temperature conditioning was accomplished by preconditioning the motors to the specifiied conditions for a minimum of 24 hr, then transferring the motor to the test stand and completing static testing within the time period required to ensure that the motors were at the desired mean bulk grain temperature at time of test.

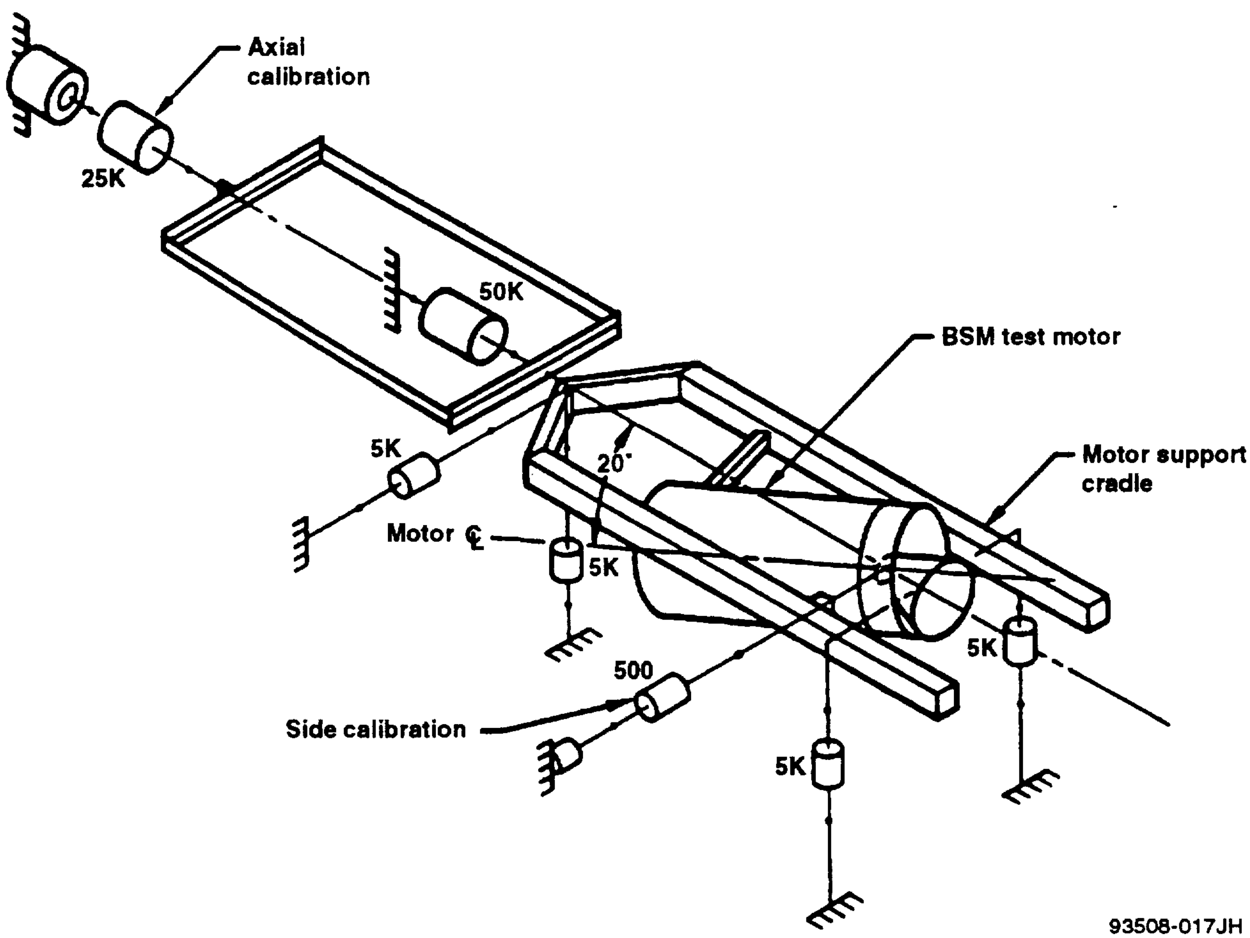


Figure 5-1. BSM Six-Component Test Stand Schematic

Thermal analyses (see Appendix F in Volume III) were conducted to provide parametric plots which were used to establish the "time out of conditioning" to achieve the desired test temperature.

Motor weights were taken both prior to conditioning and after static firing.

5.1 CERTIFICATION CRITERIA FOR STATIC TEST PERFORMANCE. The objective of the static testing of the two Delta Qualification motors was to subject the enhancements identified in Section 1 of this report to representative motor environments so the enhancements could be qualified for incorporation in BSM flight hardware.

In order for these enhancements to be validated, the motors used for their qualification were required to meet all motor ballistic performance parameters as defined in USBI specification 10SPC-0067. Specifically, the following motor performance acceptance criteria had to be met:

- Maximum web action time of 0.805 sec
- Minimum web action time total impulse of 14,000 lb-sec
- Maximum pressure at web action time of 2,000 psia
- Maximum total time of 1.050 sec
- Minimum action time total impulse of 15,000 lb-sec
- Maximum thrust of 29,000 lb
- Minimum web action time average thrust of 18,500 lb
- Ignition interval between 0.030 sec and 0.100 sec.

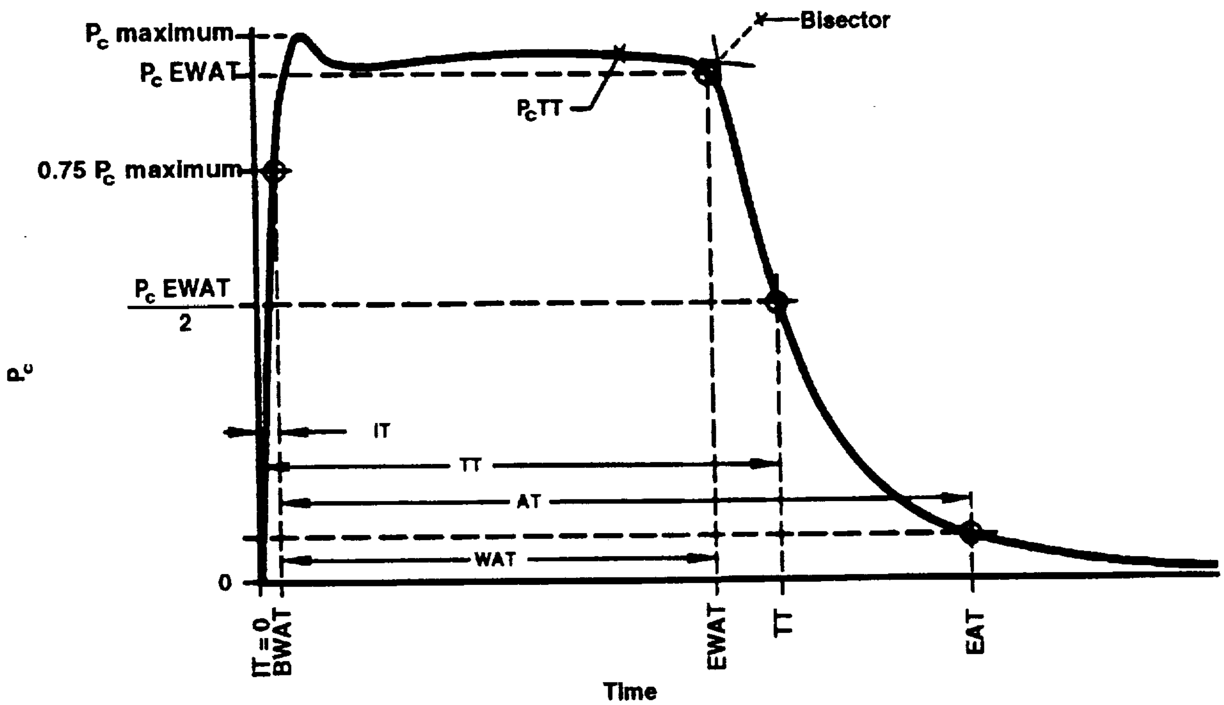
The definition of the above ballistic parameters is provided in figure 5.1-1.

5.2 STATIC TEST RESULTS. Delta Qualification motor S/N 1000738 was temperature-conditioned at 130°F (+5/-0°F), and motor S/N 1000734 was temperature conditioned at 20°F (+0/–5°F). Based on the actual temperature conditioning data, the "out of conditioning" thermal analysis (see Appendix F, Volume III), the prevailing ambient conditions at time of test, and the selected out of conditioning time, the bulk temperatures of the propellant grains at time of test were 129.5°F for motor S/N 1000738 and 22.2°F for motor S/N 1000734.

The selected "time out of conditioning" was based on obtaining bulk propellant temperatures outside of the specification requirement of 30°F and 120°F but within a range that would not lead to violation of the motor performance parameters identified above.

Motor performance acceptability was assessed by (1) engineering analysis of the test data and (2) by similarity to previously fired lot acceptance test (LAT) motors.

The primary evaluation method for motor performance was by engineering analysis wherein the results were compared with the motor performance requirements of Specification 10SPC-0067. For the analysis by similarity, the motor performance was compared to that obtained for the LATs for the BSM pre-production lot 400-2907 and the eight production Lots AAR through AAW. These are the motors which have been manufactured using the aluminum mandrels under the present BSM contract (IEWA 018333, NASA Prime Contract NAS8-36300).



Where :

P_c = chamber pressure, psia
WAT = web action time (EWAT - BWAT), sec
BWAT = beginning of web action time, sec
EWAT = end of web action time, sec
IT = ignition time, sec
TT = total time, sec
AT = action time, sec
EAT = end of action time, sec

93508-018RS

Figure 5.1-1. Ballistic Data Definitions

The high-speed motion pictures (1000 fps) were also reviewed and verified the absence of any debris in the motor plume.

5.2.1 Motor Performance by Analysis. The motor performance results based on engineering analysis of the two Delta Qualification motors are summarized in figure 5.2-1. As shown, both motors demonstrated compliance with the specification requirements, even for the intentional "overtest" conditions achieved.

Figures 5.2-2 through 5.2-5 present detailed plots of pressure versus time and axial thrust versus time for both Delta Qualification motors. As noted in the review of this data, both motors exhibited satisfactory ballistics with no anomalies evident in either the pressure or thrust data.

5.2.2 Motor Performance by Similarity. At the time of testing of the two Delta Qualification units, CSD had completed a pre-production batch and eight BSM production lots (AAR through AAY) using the aluminum casting mandrels. Each propellant batch had two LAT motors static fired, one conditioned at 30+5/-5°F and one conditioned at 120+5/-5°F, for acceptance of the propellant per SE0837 (see Appendix D in Volume III). All LATs were tested within 30 min after removal from conditioning.

Specification Parameter	Specification Criteria	S/N 1M738* (Temperature = 129.5°F)	S/N 1M734* (Temperature = 22.2°F)
Web action time, sec	0.805 maximum	0.612	0.736
Web action time total impulse, lb-sec	14,000 minimum	14,600	14,866
Pressure at web action time, psia	2,000 maximum	1,886	1,617
Total time, sec	1.050 maximum	0.781	0.937
Action time total impulse, lb-sec	15,000 minimum	18,455	18,415
Thrust, lb	29,000 maximum	24,199	20,608
Average thrust web action time, lb	18,500 minimum	23,874	20,211
Ignition interval, sec	0.030 to 0.100	0.034	0.054
*Pre-test propellant weights, lbm: S/N 1M738 = 76.7; S/N IM734 = 77.3			

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Figure 5.2-1. Delta Qualification 2 Motor Performance Summary

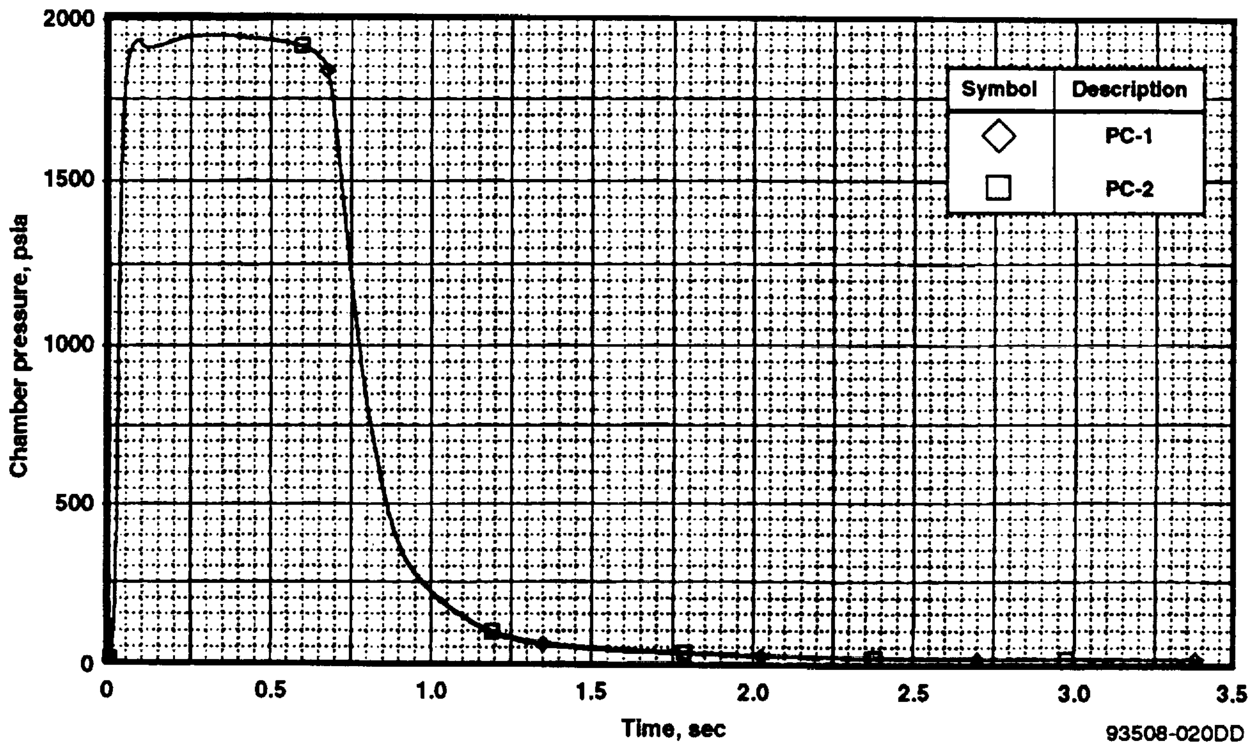


Figure 5.2-2. Chamber Pressure vs Time, Motor S/N 1000738

As a further evaluation of the performance of the two Delta Qualification motors, the engineering analyses of these two motors was compared with the performance of the LATS from the nine propellant batches.

In assessing these comparisons, it must be recognized that the two Delta Qualification motors were intentionally conditioned to, and static tested at, mean bulk grain temperatures slightly outside of the specification requirements (22.2°F actual vs 30°F required nominal and 129.5°F actual vs 120°F required nominal) to provide an "overtest" condition for the motors.

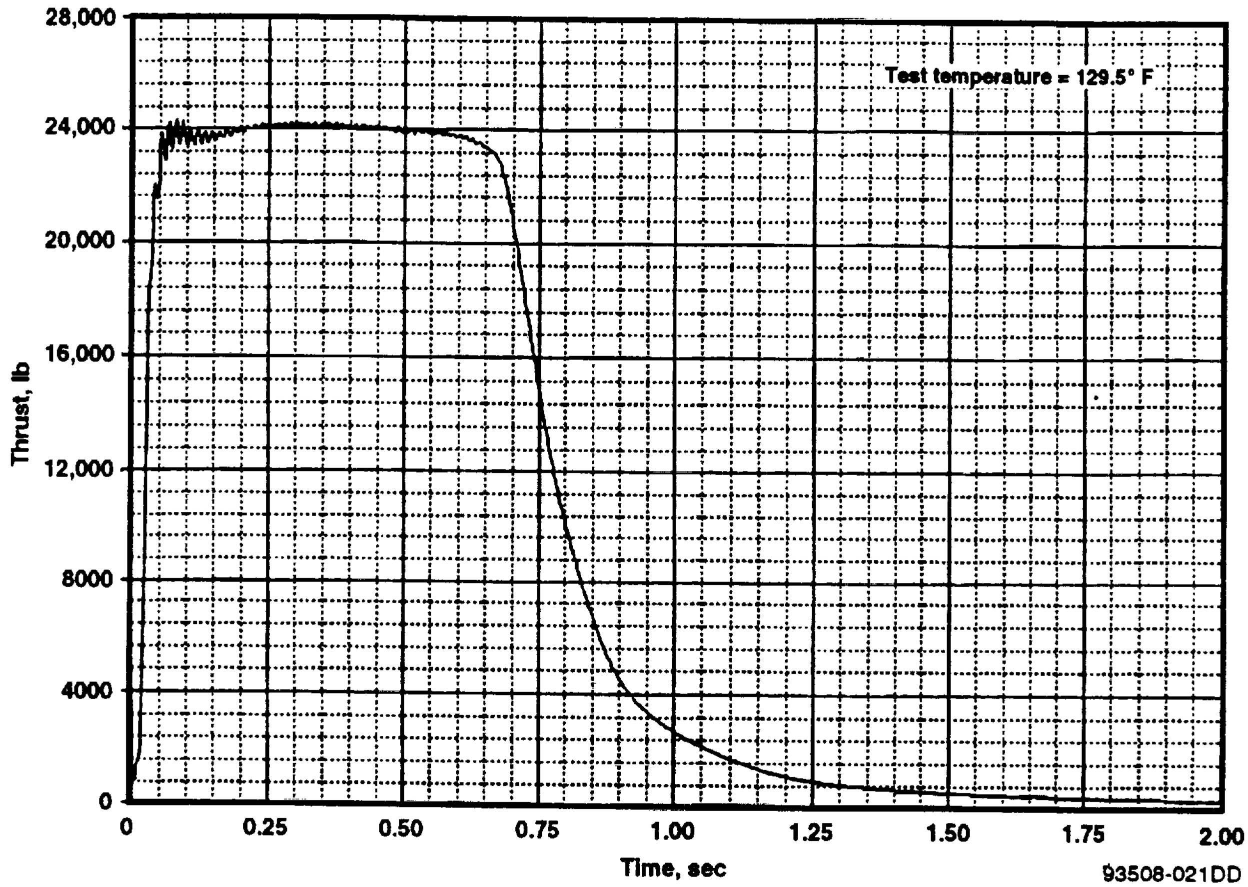


Figure 5.2-3. Thrust vs Time, Motor S/N 1000738

The comparative evaluations, which were conducted for each of the motor performance parameters identified in figure 5.2-1, are discussed in the following subsections.

Web Action Time. Figures 5.2-6 and 5.2-7 provide the comparison of the web action time (WAT) for the two Delta Qualification motors versus the LAT databases.

Since both Delta Qualification motors were intentionally conditioned and fired outside of the specification limits (22.2°F vs 30°F and 129.5°F vs 120°F), it would be expected that, for the web action time, the cold Delta Qualification motor would be biased toward the high side of the database and the hot motor biased toward the low end of the database. Review of the data comparisons in figures 5.2-6 and 5.2-7 show this to be the case.

The web action time for both motors is consistent with the LAT database and is within family. It is also consistent with LATs 1000712 and 1000727, which were the LATs from production lot AAY, the same lot from which the two Delta Qualification motors were taken.

The web action time of the two Delta Qualification motors provides additional substantiation that the two motors performed as planned and provide a valid test bed for qualification of the enhancements identified herein.

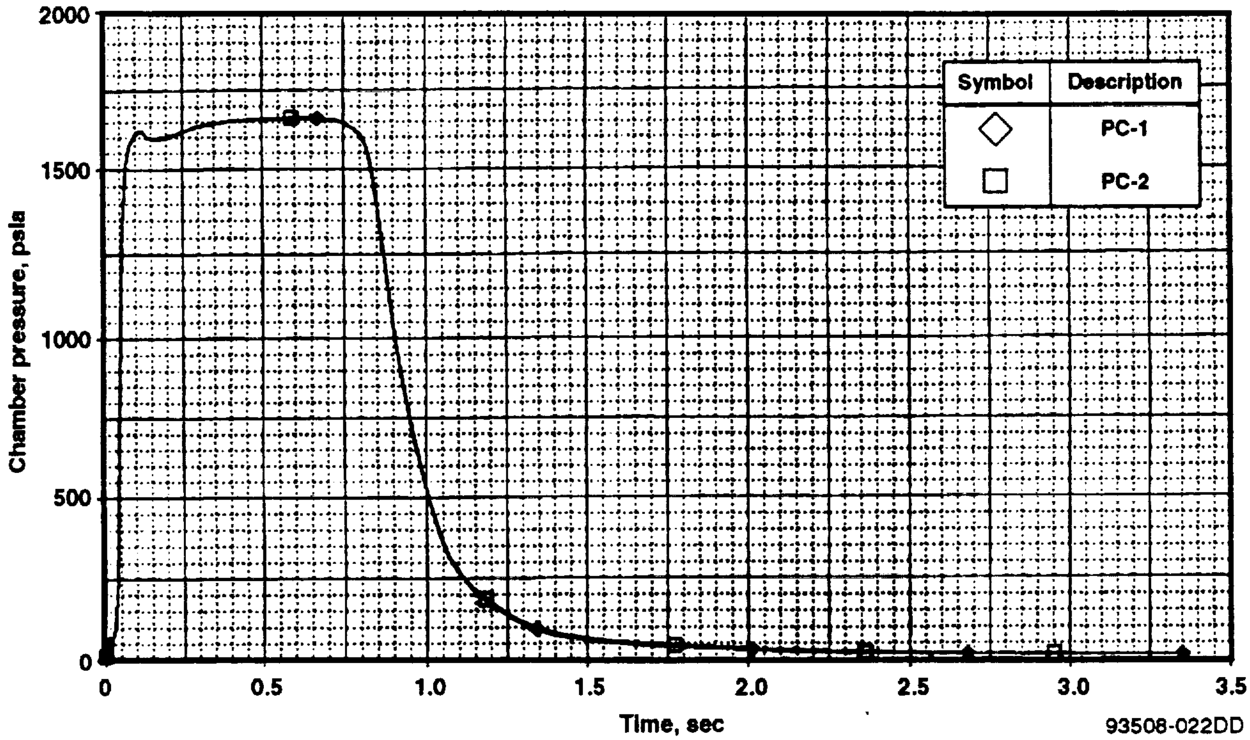


Figure 5.2-4. Chamber Pressure vs Time, Motor S/N 1000734

Web Action Time Total Impulse. The web action time total impulse is a strong function of the propellant weight and is influenced by the test temperature only to the extent that it slightly impacts the pressure trace and therefore the "definition" of web action time. The two Delta Qualification motors had propellant weights of 77.3 lb and 76.7 lb for motors S/N 1000734 and S/N 1000738. For reference, the average propellant weights of the nine 30°F LAT motors and the nine 120°F LAT motors was 76.5 lb and 76.4 lb, respectively.

The data for the web action time total impulse (see figures 5.2-8 and 5.2-9) for the Delta Qualification motors is consistent with the LAT database and supports the conclusion that the two motors are acceptable test beds for validating the enhancements for incorporation into BSM flight hardware.

Pressure at Web Action Time. Figures 5.2-10 and 5.2-11 present the comparative data for the pressure at web action time. As noted, the pressure for the motor tested at 22.2°F is biased toward the low end of the database, while the motor tested at 129.5°F is biased toward the high end of the database. In both instances this is consistent with, and is a result of, the actual test conditions of the Delta Qualification motors versus those of the LATs.

Again, specific comparisons of the two Delta Qualification units with their companion LAT units from Lot AAY show consistency in performance and demonstrates further the acceptability of the two units as validation test beds for the enhancements of interest.

Total Time. Figures 5.2-12 and 5.2-13 provide the comparison of the total time for the two Delta Qualification motors and the production lot LATs.

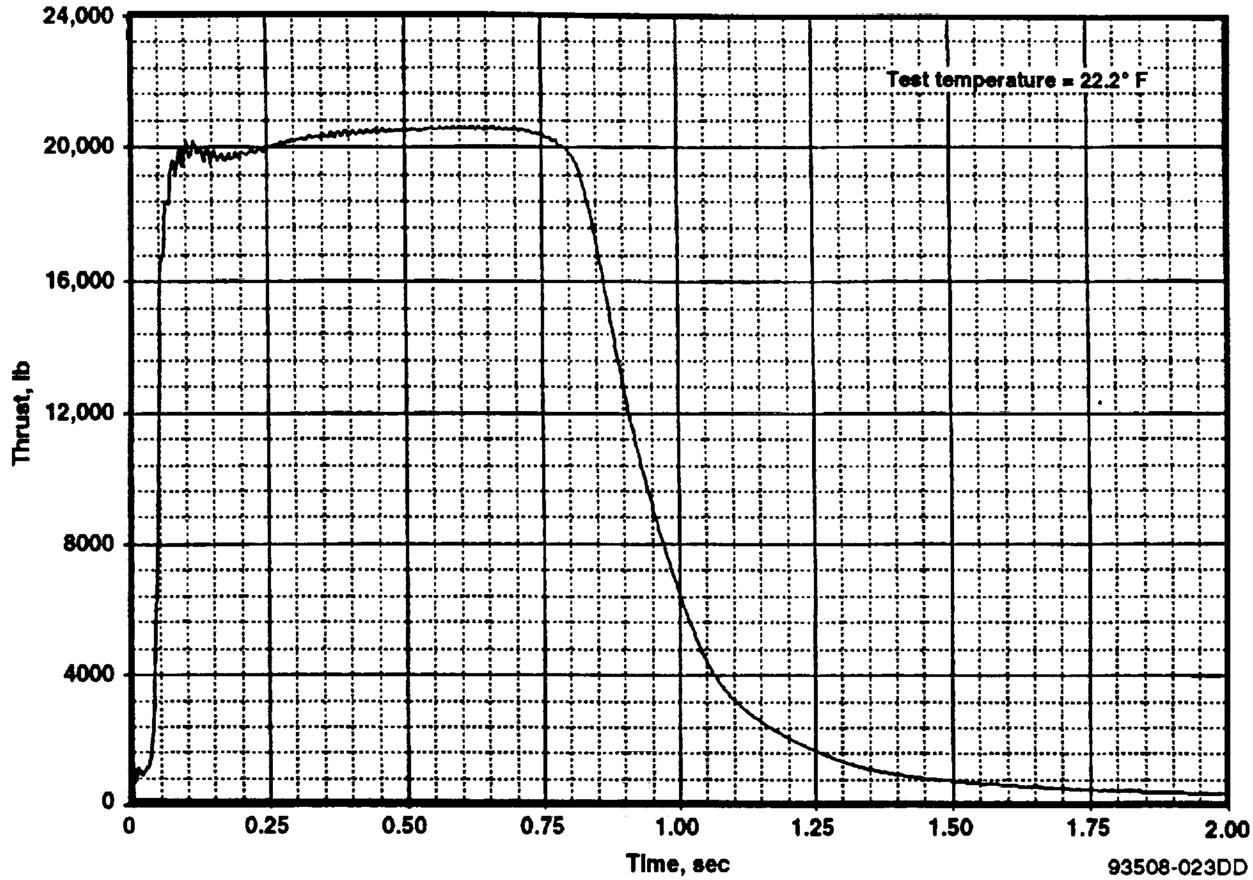


Figure 5.2-5. Thrust vs Time, Motor S/N 1000734

The comments provided with respect to the comparisons for the web action time also apply here. The comparative data is consistent with the test conditions of the two Delta Qualification motors compared to the test conditions of the LATs.

Action Time Total Impulse. Figures 5.2-14 and 5.2-15 provide the comparison of the action time total impulse of the two Delta Qualification motors to that of the LAT databases at 30°F and 120°F test conditions. As with the web action time total impulse, the action time total impulse is a strong function of the propellant weight and is a function of the test temperature only to the extent that it may slightly impact the calculation of the action time upon which the impulse calculation is made.

Examination of the data in figures 5.2-14 and 5.2-15 show the motor behavior to be nominal and consistent with he propellant weights as summarized in the discussion of the web action time total impulse.

Maximum Thrust. Figures 5.2-16 and 5.2-17 provide the comparison of the maximum thrust for the Delta Qualification motors and the production lot LATs. The data is nominal with the cold motor providing a slightly lower maximum thrust than its companion motor from lot AAY (i.e., motor S/N 1000734 vs motor S/N 1000712), and the hot motor providing a slightly higher maximum thrust than its companion motor (i.e., motor S/N 1000738 vs motor S/N 1000727). Both data sets are consistent with the test temperatures.

Web Action Time Average Thrust. Figures 5.2-18 and 5.2-19 provide the comparison of the web action time average thrust for the two Delta Qualification motors and the production lot LATs. The average thrust is a function of the test temperature and of the propellant weight in that the weight is a direct function of the grain length and hence the burn surface area. It is expected that the average thrust for the motor tested at 22.2°F would be biased toward the low side of the 30°F database, and the motor fired at 129.5°F would be biased toward the high side of the 120°F database.

Examination of the data presented in figures 5.2-18 and 5.2-19 show that the thrust data for the two Delta Qualification motors is biased as expected due to the test temperatures for the Delta Qualification motors.

As with the preceding parameters, the web action time average thrust confirms the acceptability of the performance of both Delta Qualification motors in qualifying the enhancements in flight hardware.

Ignition Interval. Figures 5.2-20 and 5.2-21 present the ignition interval comparisons between the two Delta Qualification motors and the BSM LATs. Review of this data shows that the ignition interval for the Delta Qualification motor fired at 129.5°F is the lowest achieved to date. The drop in this time interval is particularly noticeable when lot AAY LAT motor S/N 1000727 is compared with the lot AAY Delta Qualification motor S/N 1000734.

This shortening of the ignition interval, while consistent with the higher than normal test temperature, is of particular interest in that it is the primary driver in establishing the erosion characteristics of the primary O-ring seal between the case and closure. The charging of the O-ring cavity and the seating of the O-ring takes place during the ignition interval (reference CSD Action Item 026, which is included in Volume III as Appendix K). The faster the ignition interval (e.g., the higher the grain bulk temperature), the shorter the ignition interval will be and the higher the flow rate into the O-ring cavity during charging until the O-ring is seated.

The result of these events leads to the possibility that the O-ring erosion on the Delta Qualification motor S/N 1000738 fired at 129.5°F will exhibit a bias to the high side in terms of the primary O-ring erosion.

The results of the O-ring evaluations are discussed in Section 6.

5.3 CONCLUSIONS. Both Delta Qualification 2 motors performed to specification requirements. Pre-static test visual and propellant grain x-ray inspection identified no anomalous conditions. Based on the recorded motor data and review of the high speed (i.e., 1000 fps) movie films, the following conclusions with respect to the pre-static and static testing of the two Delta Qualification 2 motors are provided:

- Environmental testing of the two Delta Qualification 2 motors conducted at MSFC (see Section 4 and Volume II of this report) prior to their static testing was completed as required; all test deviations were properly documented by MSFC, were of minor nature, and did not impose unacceptable environments on the motors; no adverse impact on the motors was identified due to the imposition of the realized environments.

- The two Delta Qualification 2 motors were properly temperature conditioned prior to static tests.
- The two Delta Qualification motors were static tested as planned at mean propellant bulk temperatures which were outside of the specification requirements, thus providing the desired "overtest" condition.
- Based on engineering evaluation of the test data, both motors met all static test specification performance requirements.
- Additional analysis by similarity by comparing the performance of both Delta Qualification motors to that of other LATs, further demonstrated that the two motors were typical BSMs and provided nominal performance consistent with the propellant bulk temperatures at time of test.
- Based on the evaluations of the Delta Qualification motors, they provided the proper performance for qualifying the enhancements evaluated herein (see Section 6) for incorporation into BSM flight hardware.

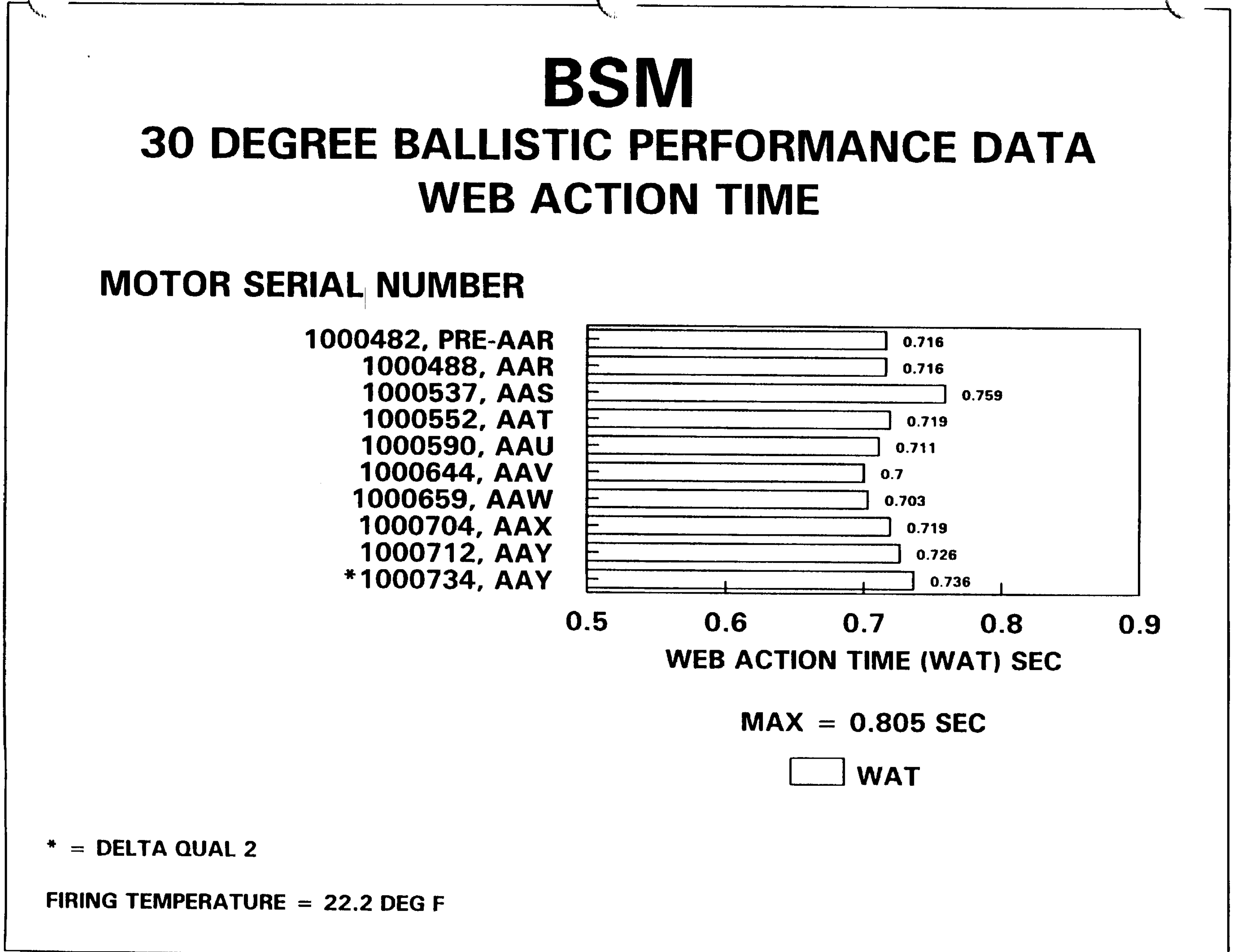


Figure 5.2-6. Web Action Time Comparison, Motor S/N 1000734 (22.2°F)

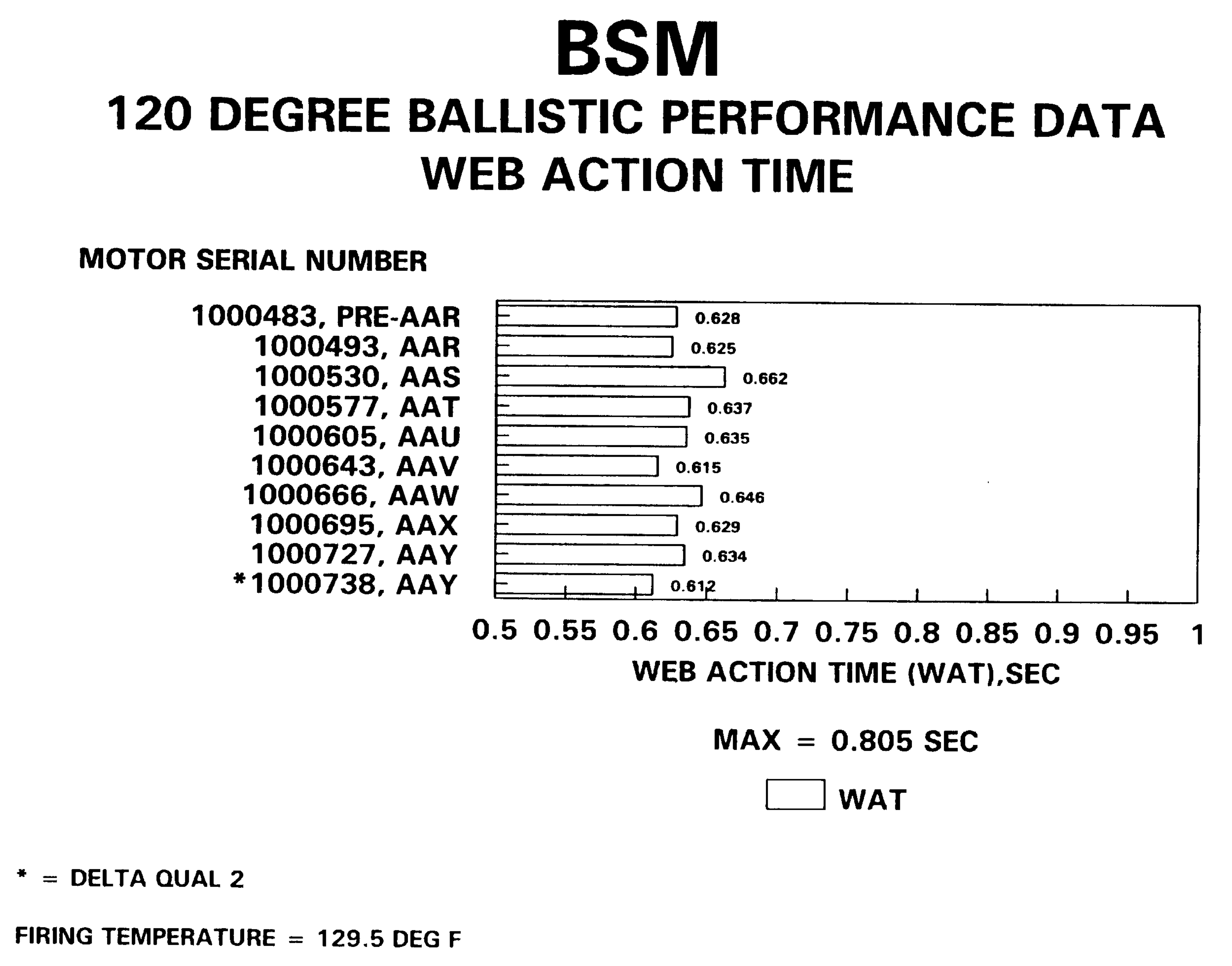


Figure 5.2-7. Web Action Time Comparison, Motor S/N 1000738 (129.5°F)

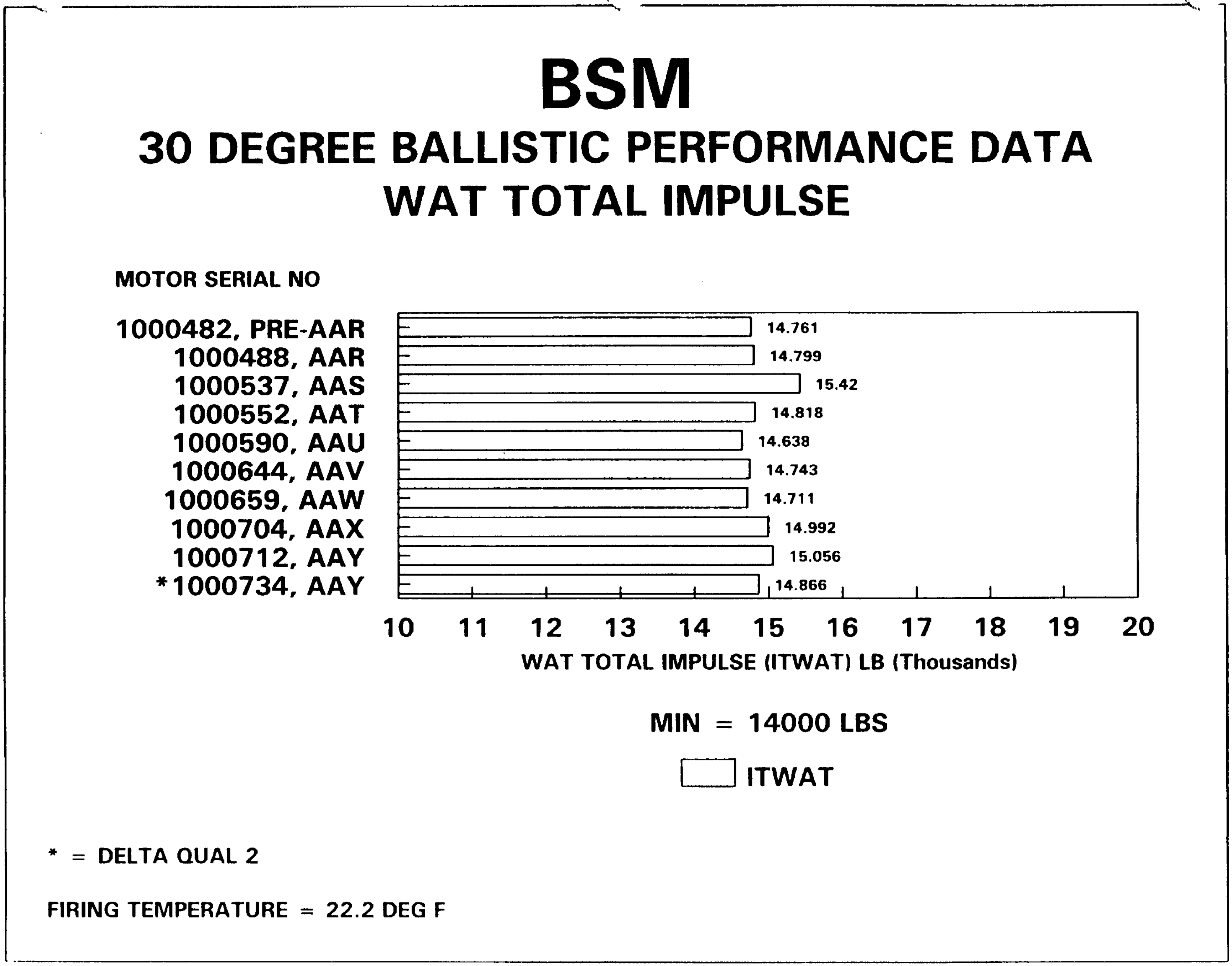


Figure 5.2-8. Web Action Time Total Impulse Comparison, Motor S/N 1000734 (22.2°F)

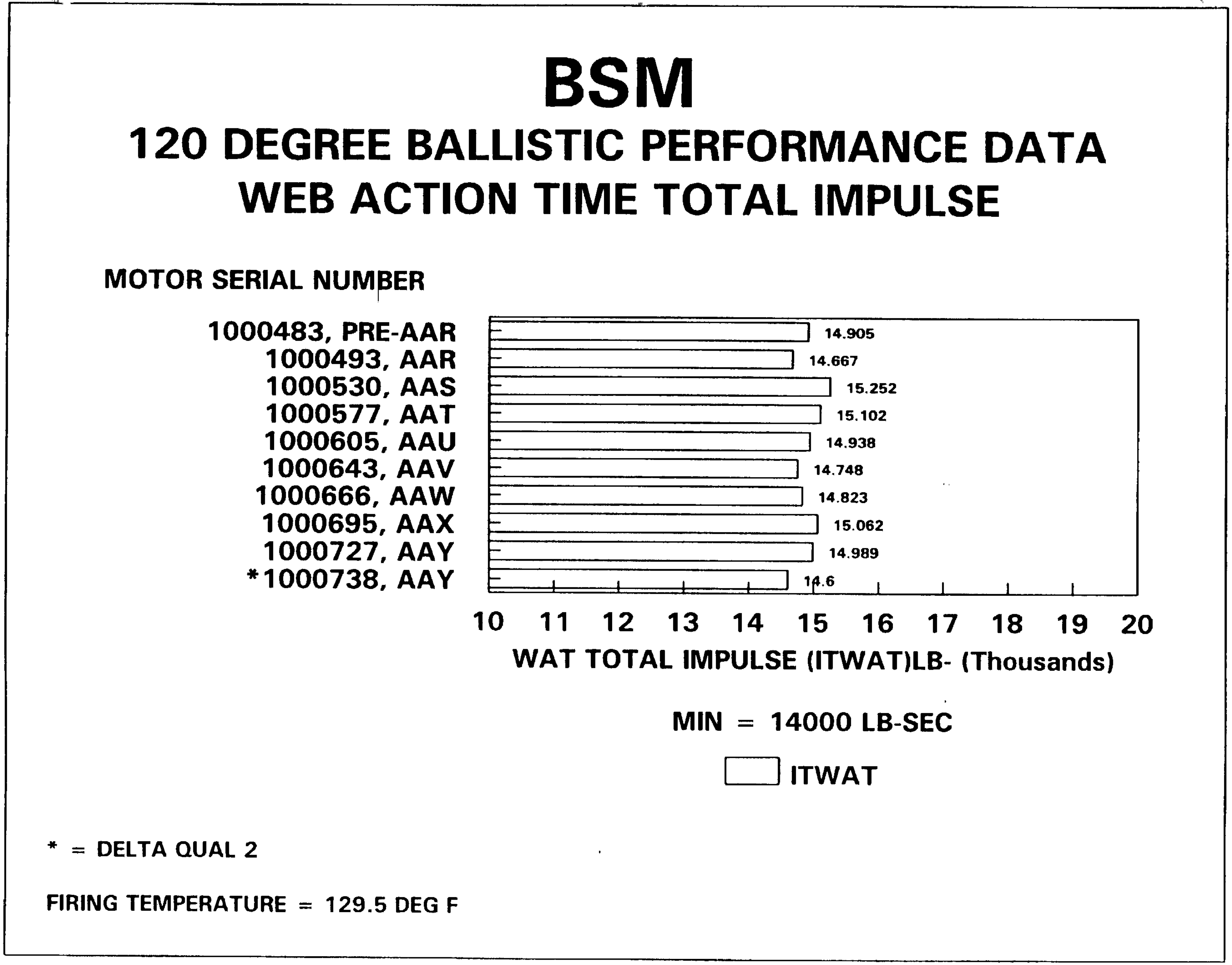


Figure 5.2-9. Web Action Time Total Impulse Comparison, Motor S/N 1000738 (129.5°F)

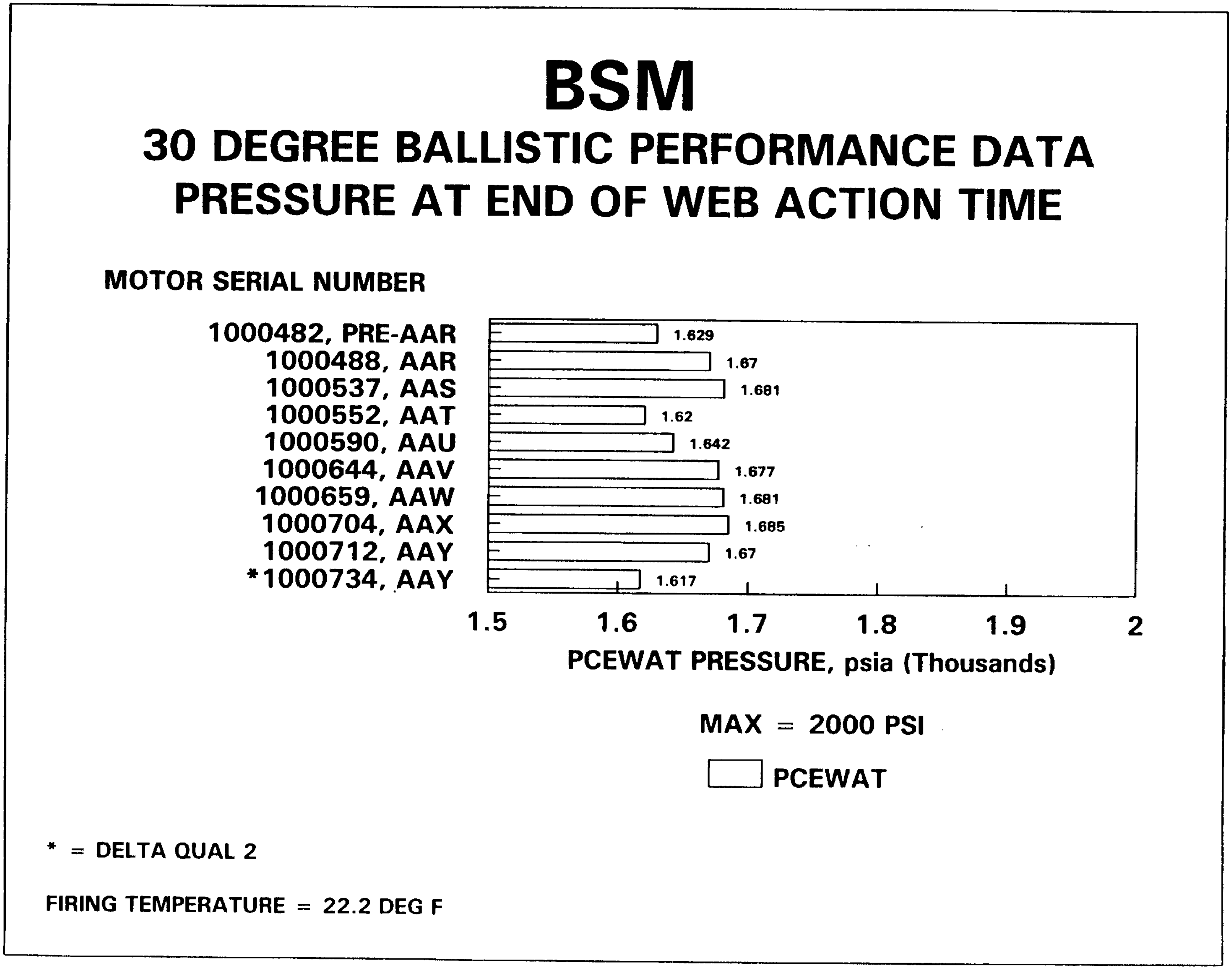


Figure 5.2-10. Pressure at Web Action Time Comparison, Motor S/N 1000734 (22.2°F)

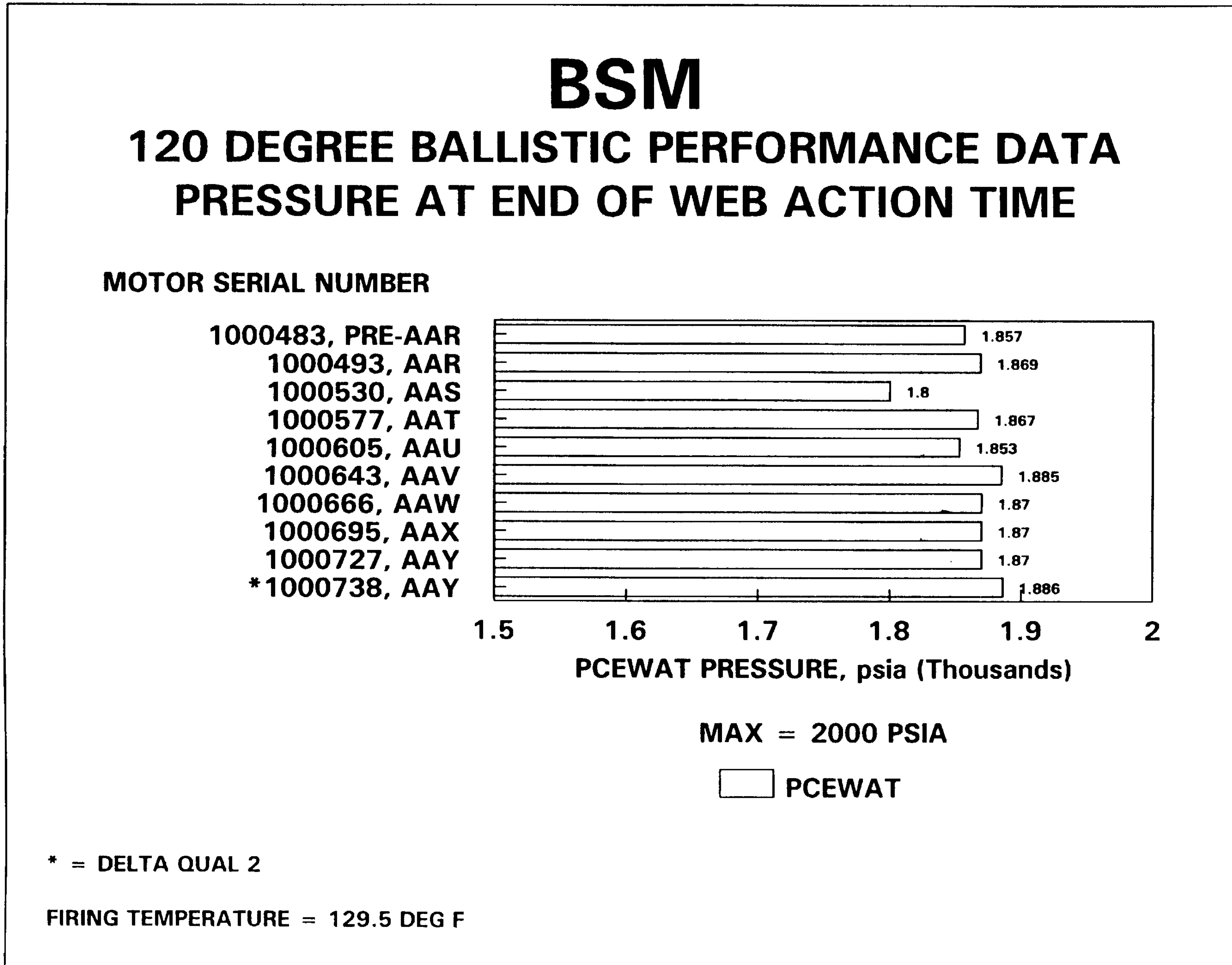


Figure 5.2-11. Pressure at Web Action Time Comparison, Motor S/N 1000738 (129.5°F)

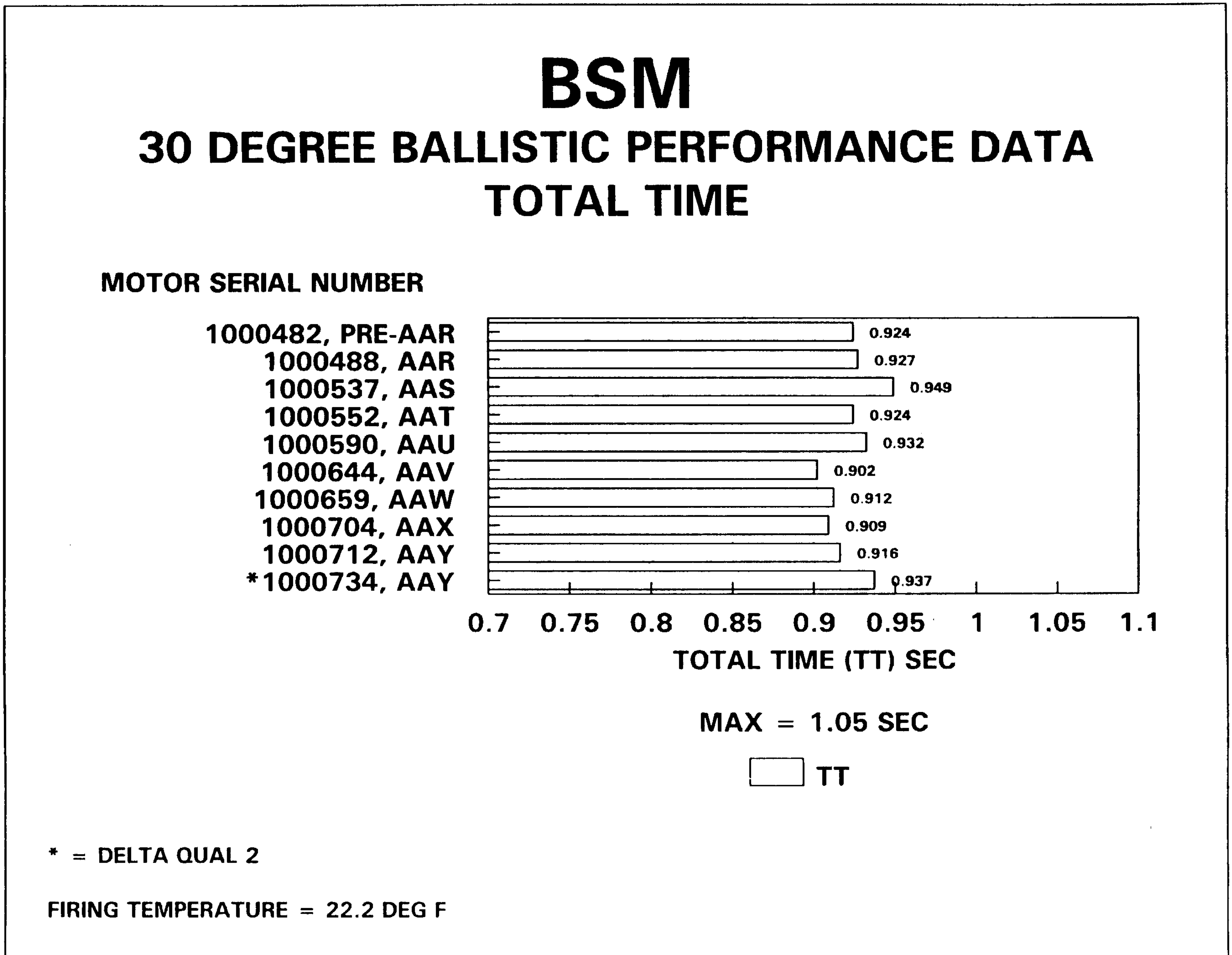


Figure 5.2-12. Total Time Comparison, Motor S/N 1000734 (22.2°F)

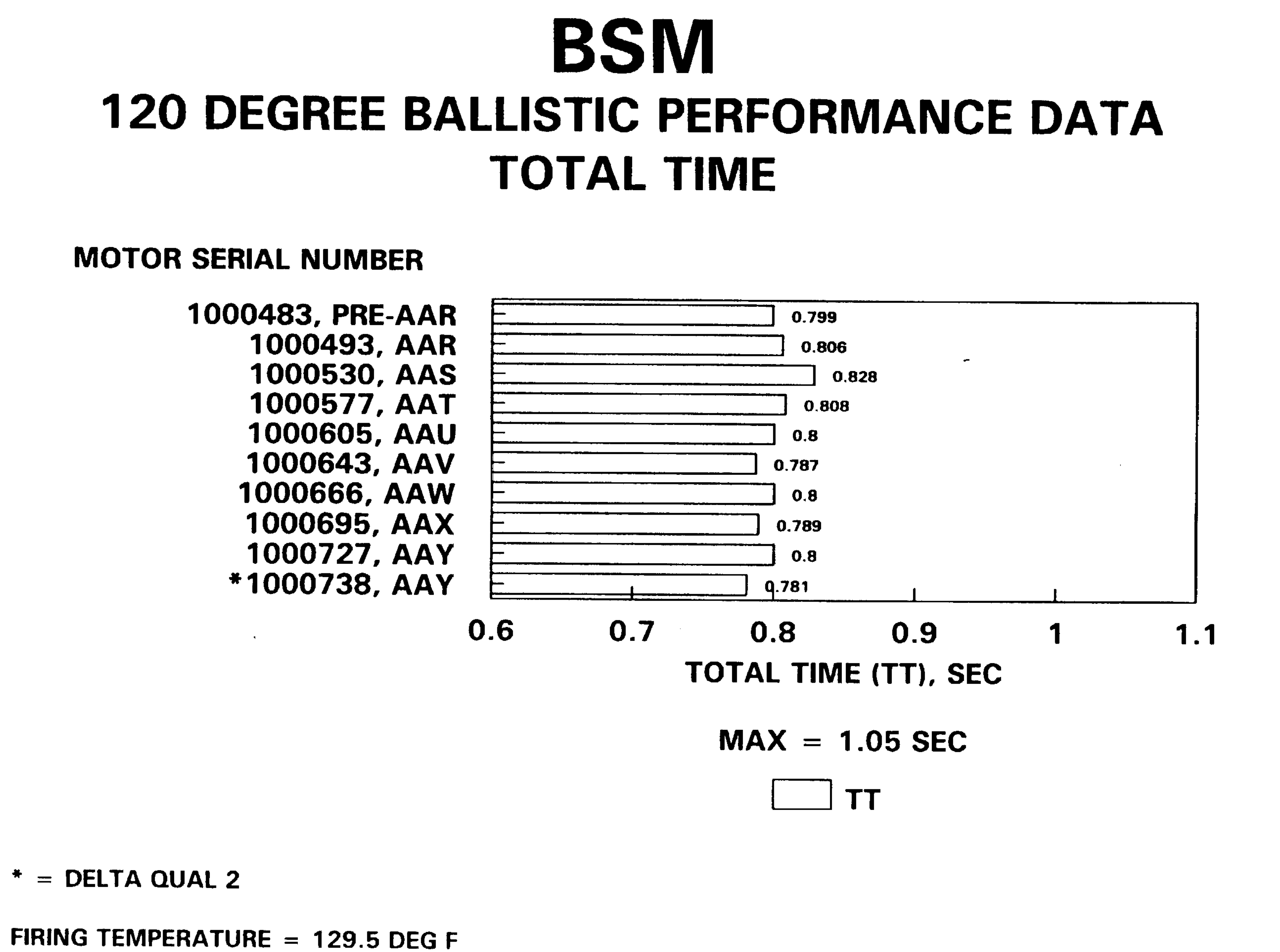


Figure 5.2-13. Total Time Comparison, Motor S/N 1000738 (129.5°F)

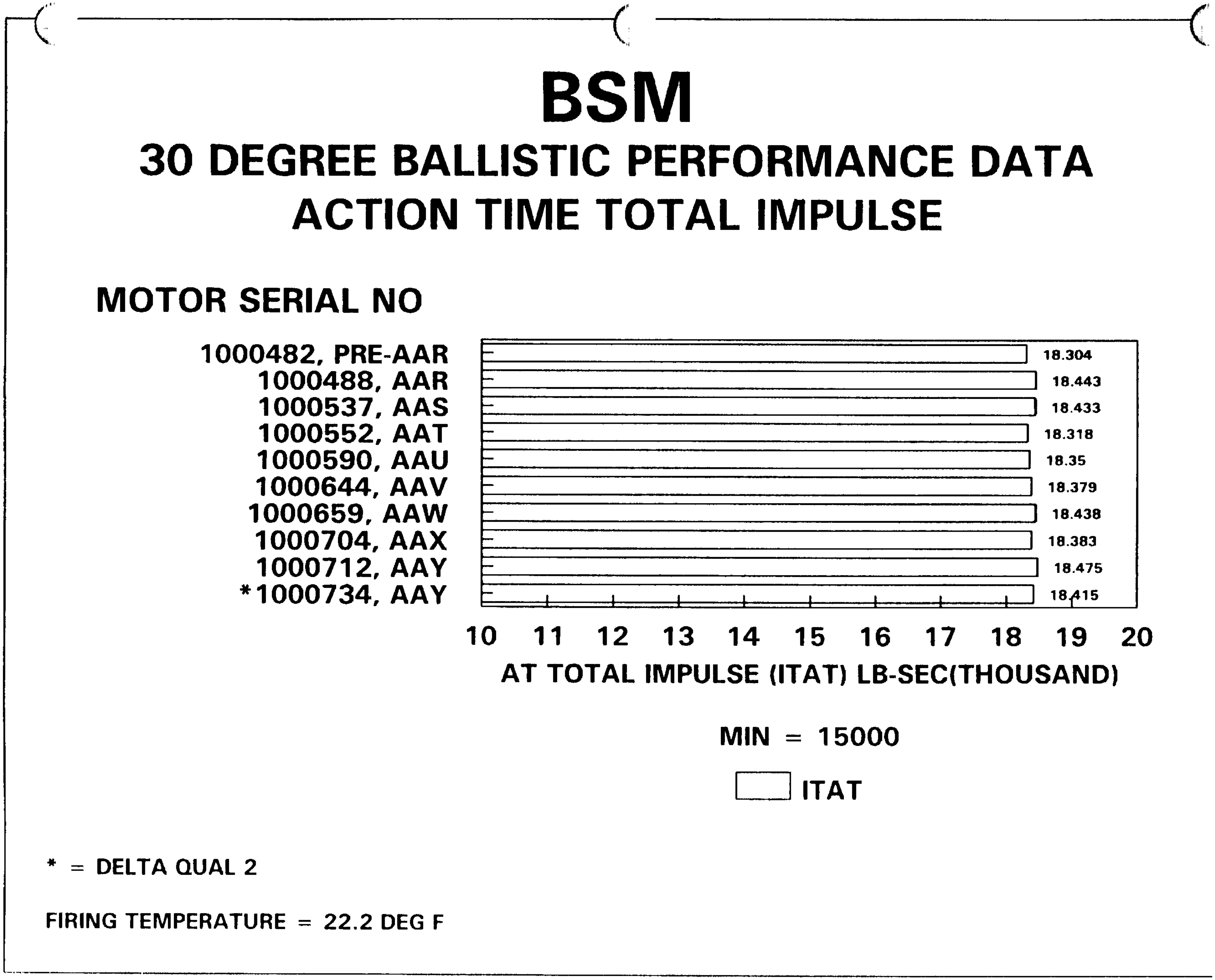
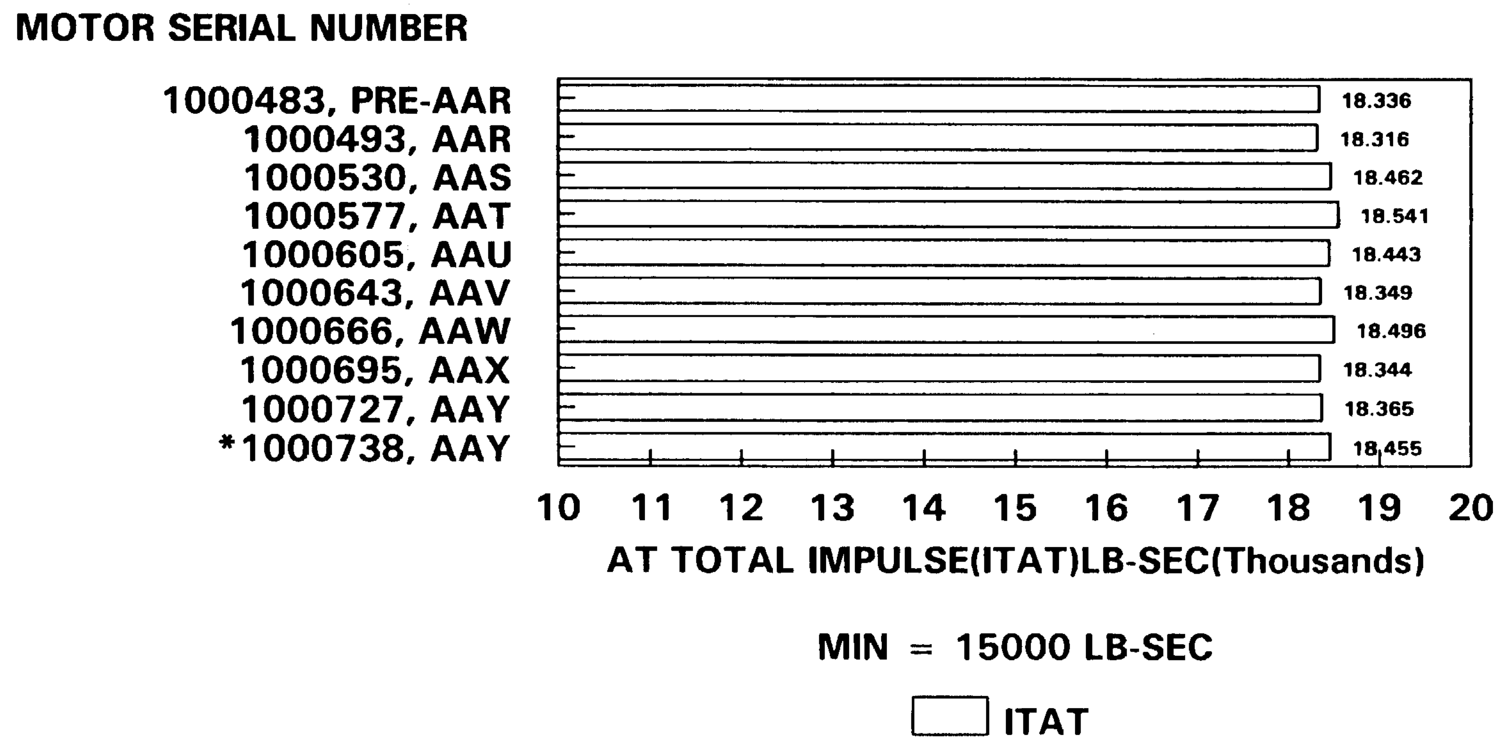


Figure 5.2-14. Action Time Total Impulse Comparison, Motor S/N 1000734 (22.2°F)

BSM

120 DEGREE BALLISTIC PERFORMANCE DATA
ACTION TIME TOTAL IMPULSE



* = DELTA QUAL 2

FIRING TEMPERATURE = 129.5 DEG F

Figure 5.2-15. Action Time Total Impulse Comparison, Motor S/N 1000738 (129.5°F)

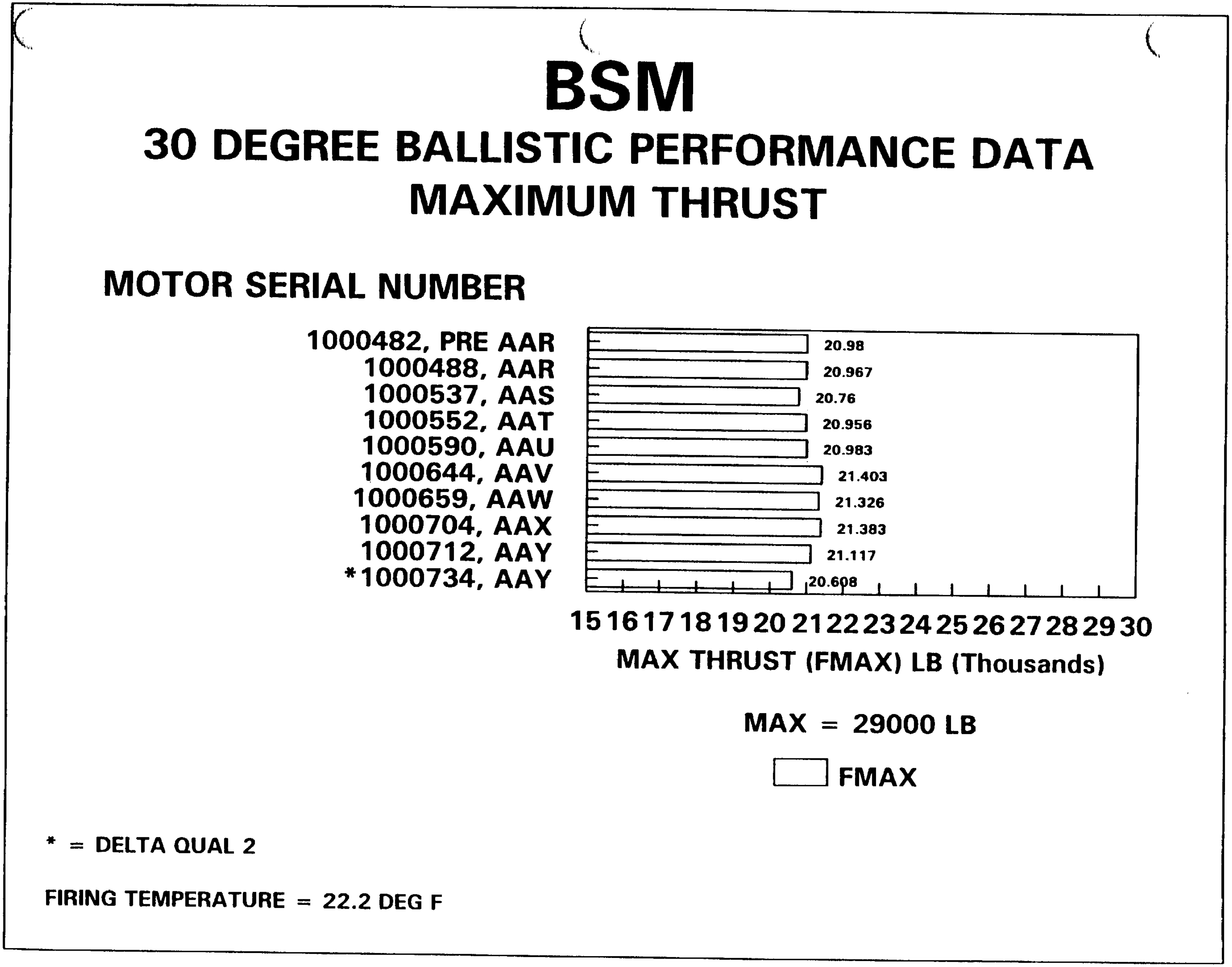


Figure 5.2-16. Maximum Thrust Comparison, Motor S/N 1000734 (22.2°F)

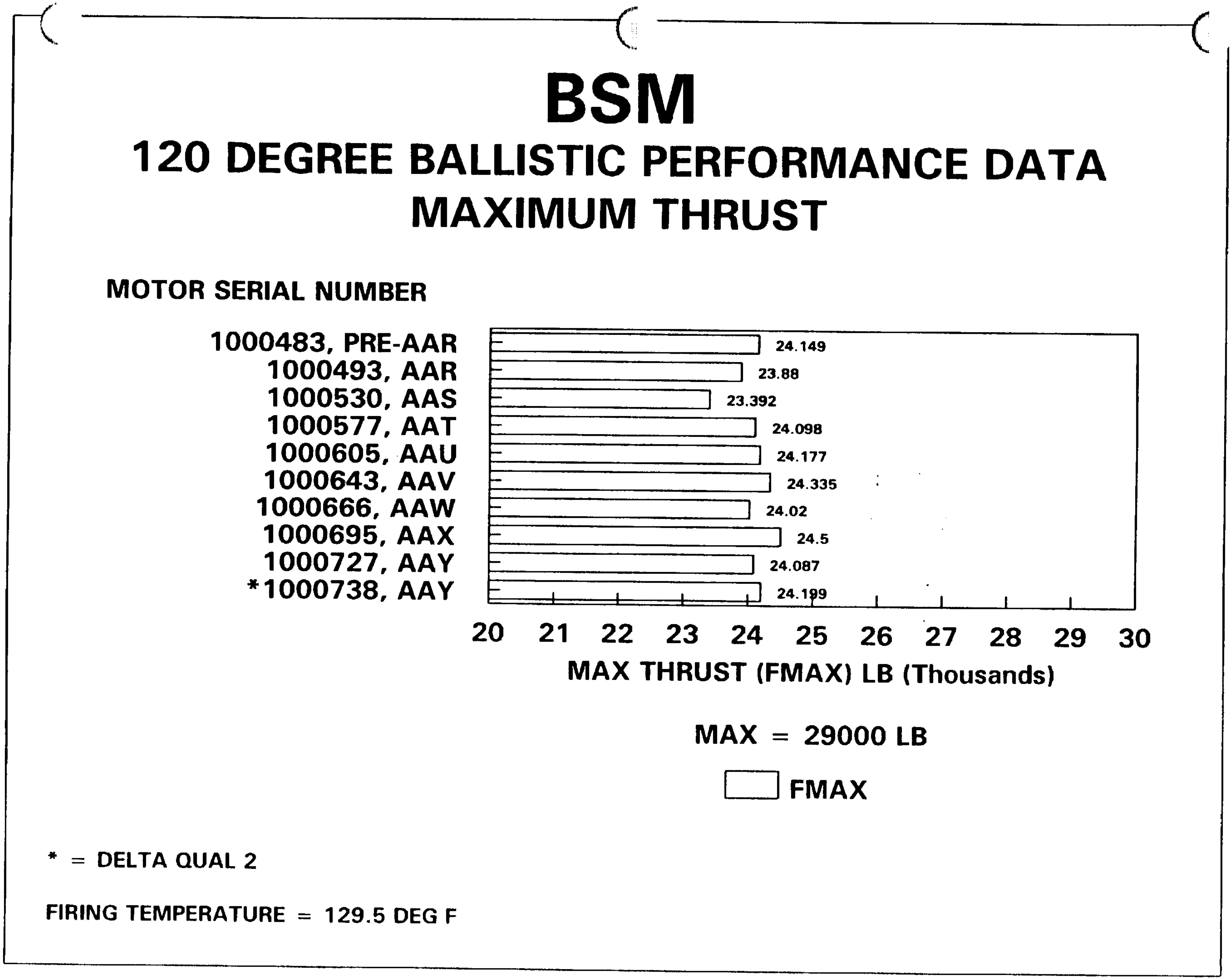


Figure 5.2-17. Maximum Thrust Comparison, Motor S/N 1000738 (129.5°F)

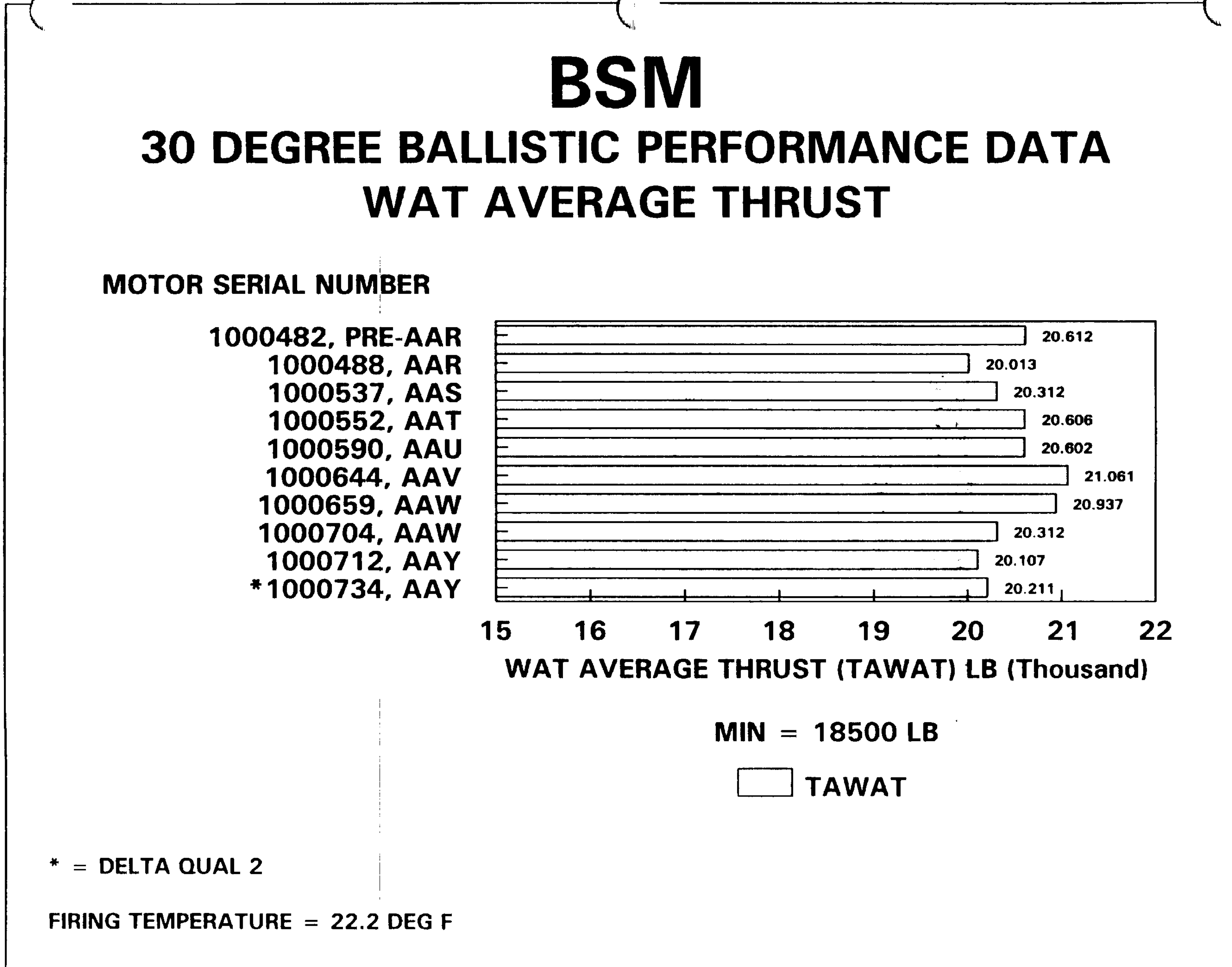


Figure 5.2-18. Web Action Time Average Thrust Comparison, Motor S/N 1000734 (22.2°F)

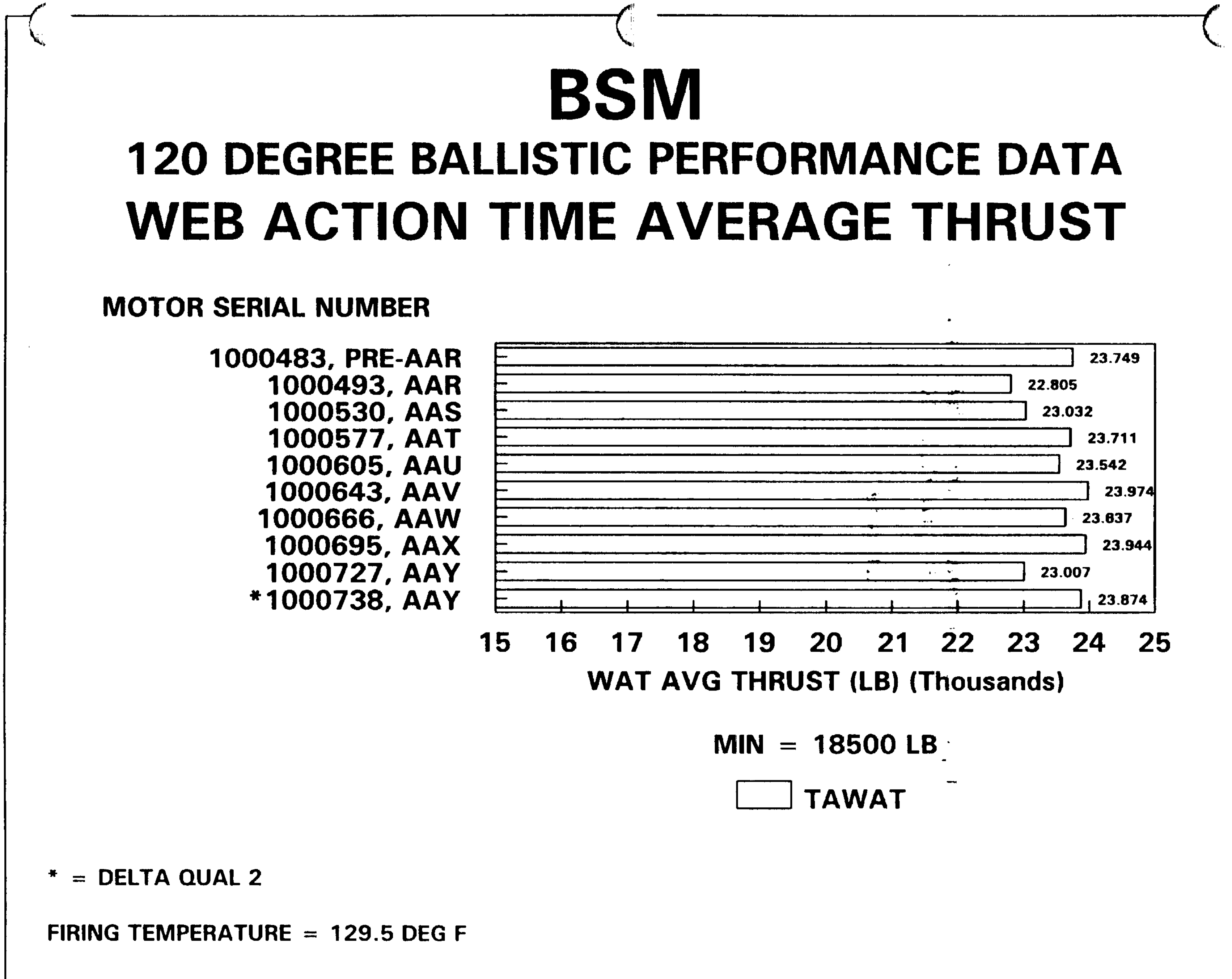


Figure 5.2-19. Web Action Time Average Thrust Comparison, Motor S/N 1000738 (129.5°F)

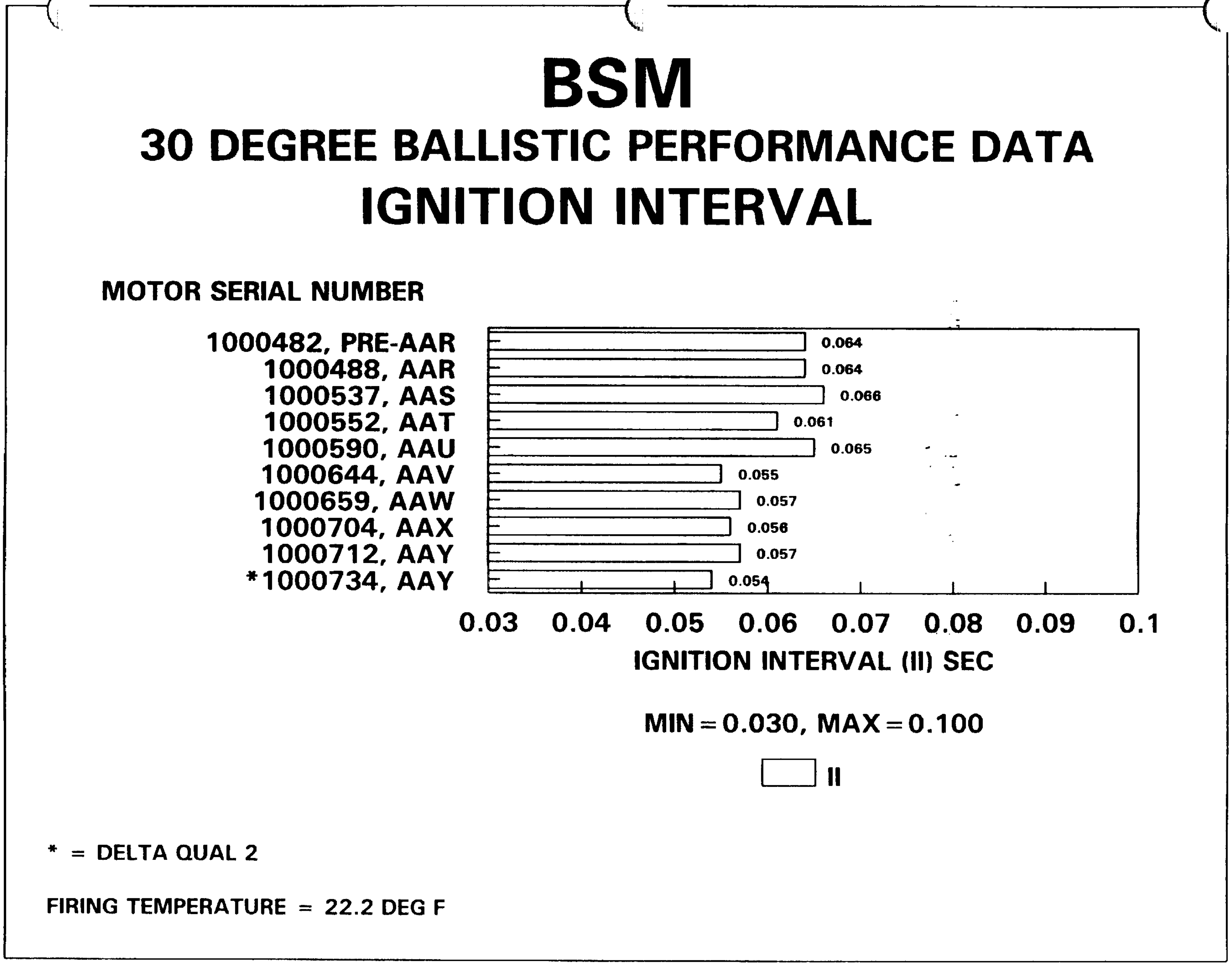


Figure 5.2-20. Ignition Internal Comparison, Motor S/N 1000734 (22.2°F)

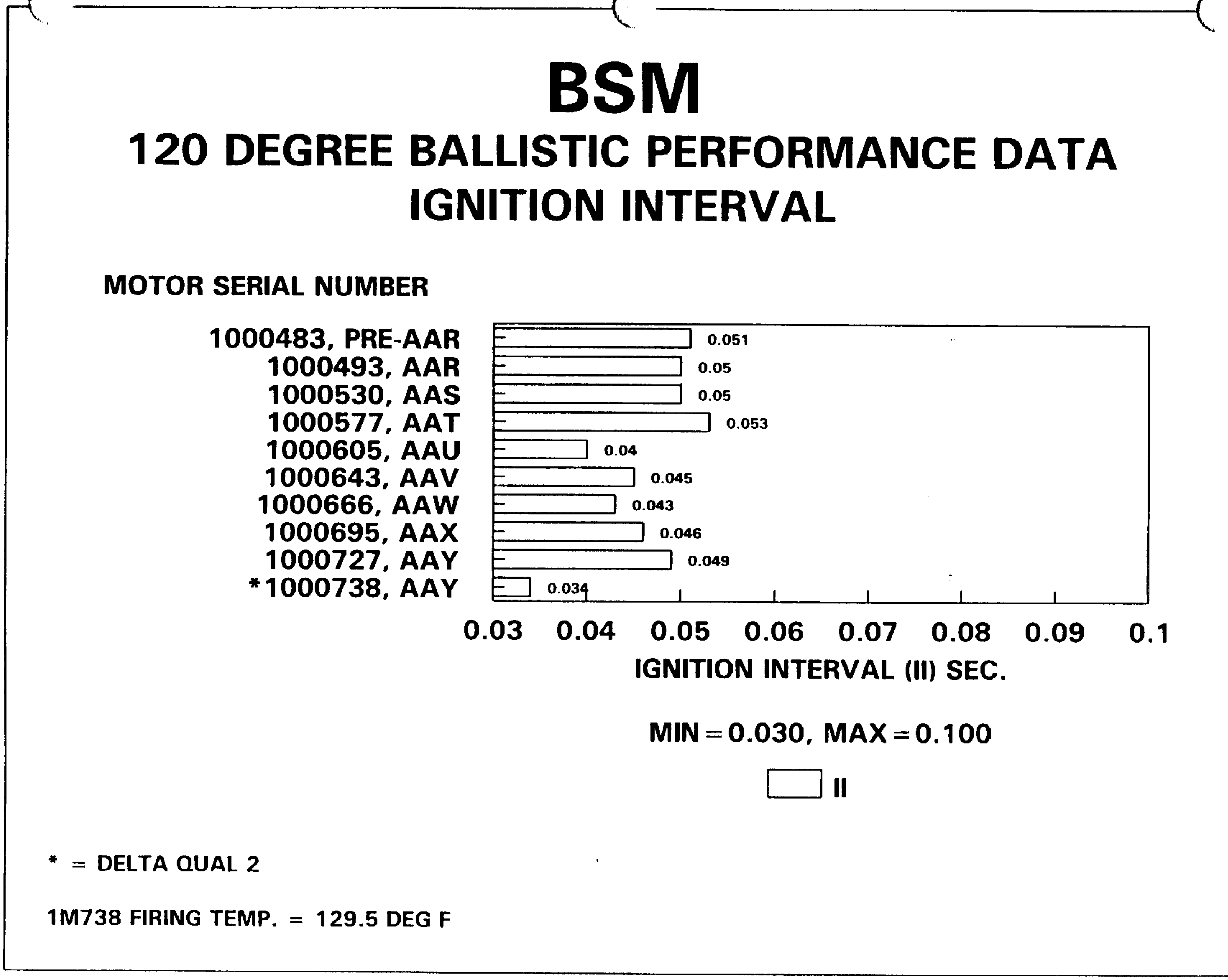


Figure 5.2-21. Ignition Internal Comparison, Motor S/N 1000738 (129.5°F)

Section 6
POSTFIRE EXAMINATIONS

Sections 4 and 5 of this report addressed, respectively, the pre-static firing environmental tests and the static testing of the two Delta Qualification motors. As noted in those discussions, the motors were verified to have been subjected to the correct environments and to subsequently have met all motor performance requirements. As such they provide a valid basis for qualifying the design enhancements addressed herein for incorporation into flight BSMs.

This section addresses the post-static test results and evaluations for each of the enhancements. Subsections 6.1 and 6.2 address posttest motor visual inspection results and the detailed O-ring examination results, respectively.

Subsections 6.3 through 6.9 describe the TQM enhancements incorporated into the Delta Qualification motors, identify the success criteria against which the performance of each enhancement was assessed, discuss the test results, and based on these results, provide conclusions and recommendations with respect to the qualification status and incorporation of each enhancement into BSM flight hardware.

6.1 VISUAL INSPECTION OF MOTOR ASSEMBLY. The motors were inspected on the test stand before and after the static firings. There were no anomalies identified with either the motors or with their installation prior to test. Posttest examination identified no external anomalies on either motor. There was no evidence of combustion gas leakage at any of the interfaces. There was no evidence of any hot spots on the external surfaces of the motor cases, igniter adapters or nozzle closures.

The confined detonating fuzes (CDFs), two each on each motor, functioned properly.

It was noted on aft motor S/N 1000734, which was fired at 22.2°F, that one of the CDF lines, when it was initiated, severed the thermocouple wire leading to the motor case and the thermocouple did not function during the firing.

After the motors were removed from the stand, the through bulkhead initiators (TBIs) were removed and all were found to have fired as planned.

The pre- and post-static conditions of both Delta Qualification motors are documented in the following subsections.

6.1.1 Motor S/N 1000734, Test Temperature 22.2°F. Figures 6.1-1 and 6.1-2 show forward and aft pretest views of motor S/N 1000734 (22.2°F). Figure 6.1-3 shows a pretest side view of the same motor. This photograph was taken prior to motor installation into the test stand for clarity of the motor view.

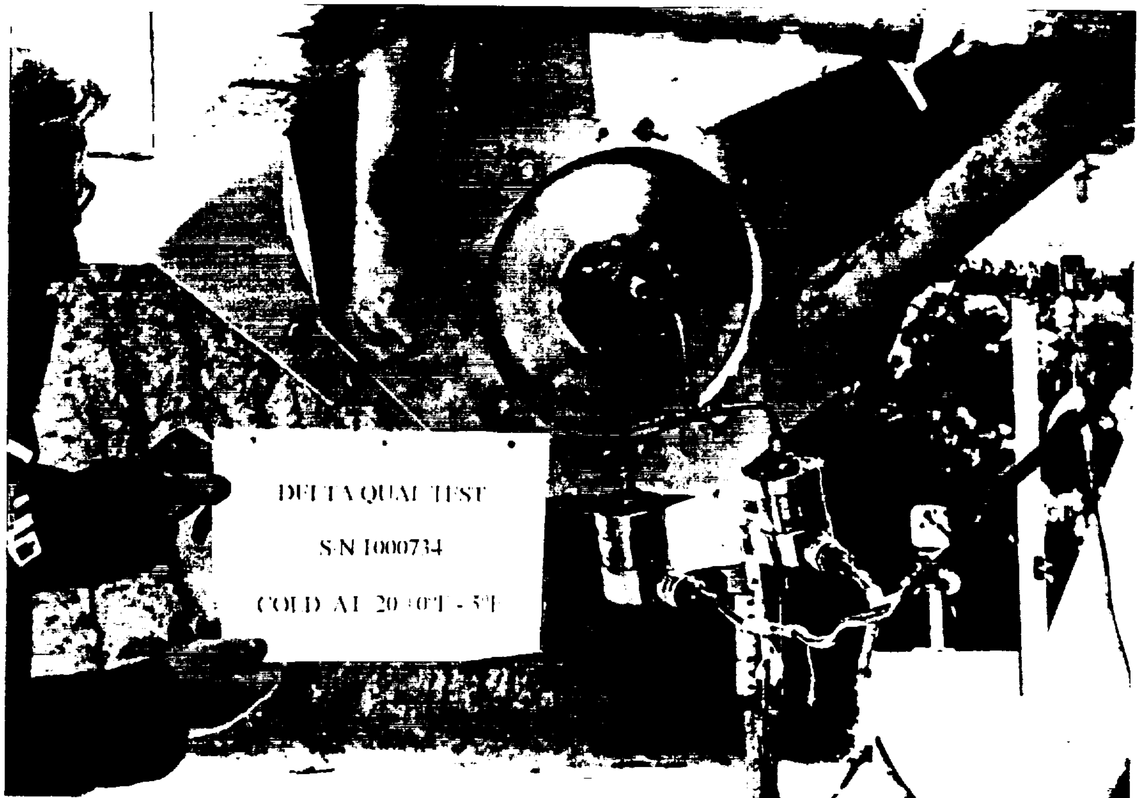


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Figure 6.1-1. Motor S/N 1000734 (22.2°F), Pretest Forward View

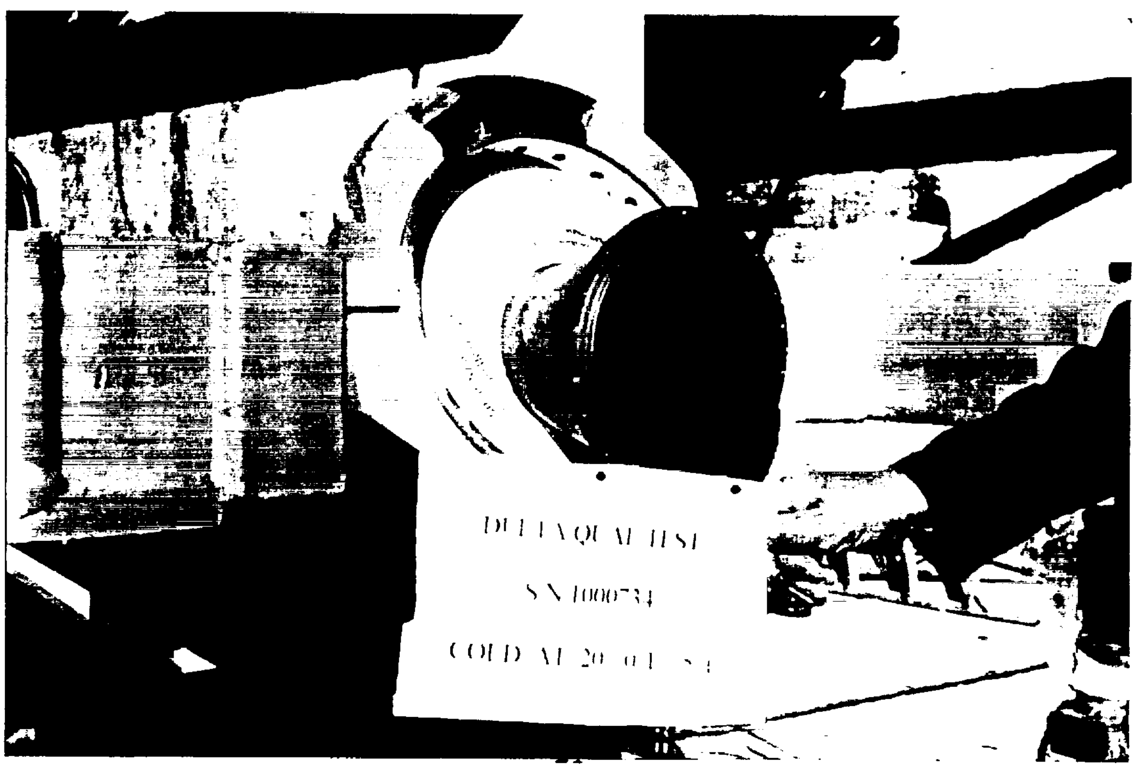

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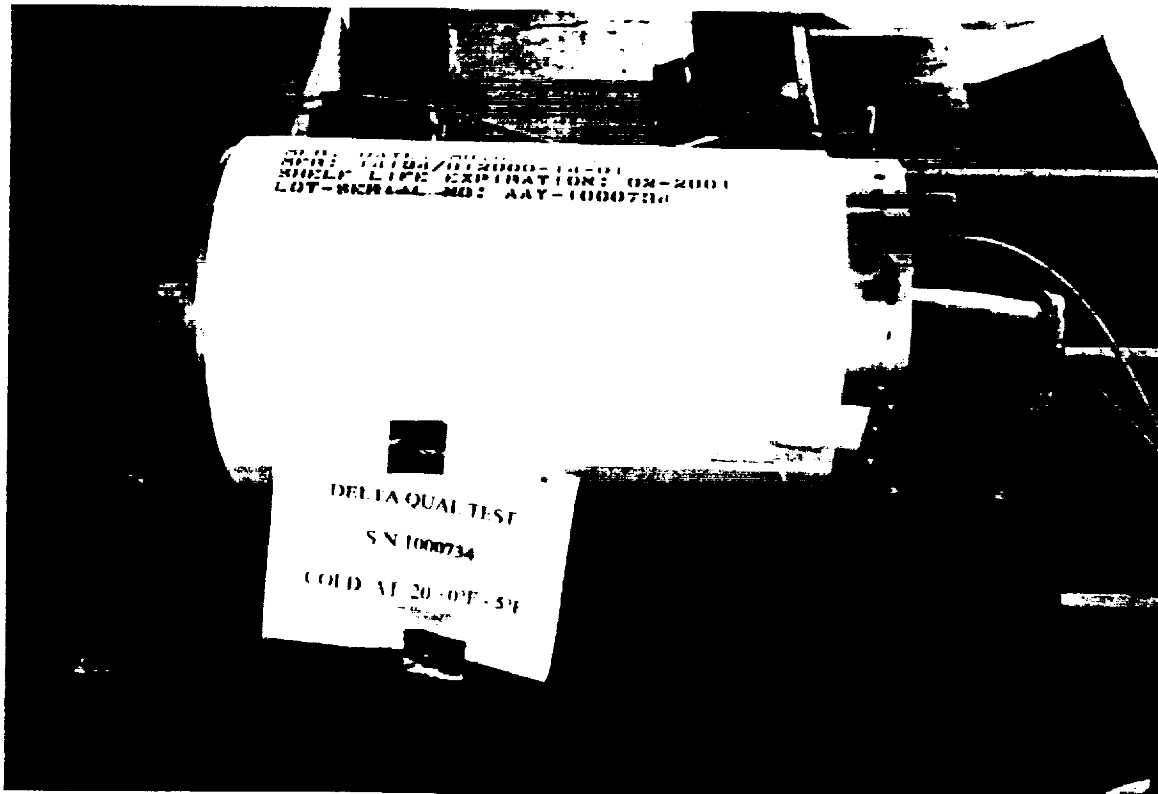
Figure 6.1-2. Motor S/N 1000734 (22.2°F), Pretest Aft View



C20933-12

Figure 6.1-3. Motor S/N 1000734 (22.2°F), Pretest Side View

Figures 6.1-4 and 6.1-5 show comparable forward and aft posttest photographs of motor S/N 1000734. Figure 6.1-6 shows the motor posttest side view. As noted above, posttest examination of the motor found it to be in excellent condition. There were no indications of any gas leakage, hot spots or cork/paint anomalies. Figure 6.1-7 shows the internal condition of the postfired S/N 1000734 motor case. The figure shows the typical condition with the liner totally intact, a small amount of char resulting from the motor tailoff and posttest heat soakout, and indications of the grain pattern.

This, combined with the results of the motor performance analyses addressed in Section 5, demonstrates that this motor provided the proper test bed for evaluation of the enhancements as discussed in subsections 6.3 through 6.8 of this report.

6.1.2 Motor S/N 1000738, Test Temperature 129.5°F. Figures 6.1-8, 6.1-9 and 6.1-10 show the pretest forward, aft and side views, respectively, of motor S/N 1000738 (129.5°F). Figures 6.1-11 and 6.1-12 show forward and aft posttest views of the motor. Figures 6.1-13 and 6.1-14 show posttest photographs of the sides of the motor. There were no anomalies noted.

Figures 6.1-15 and 6.1-16 provide posttest closeup views of the RTV bead between the closure and nozzle subassemblies. The "baking out" of this RTV bead was typical of that associated with this motor configuration as documented on all forward motor LATs conducted to date.

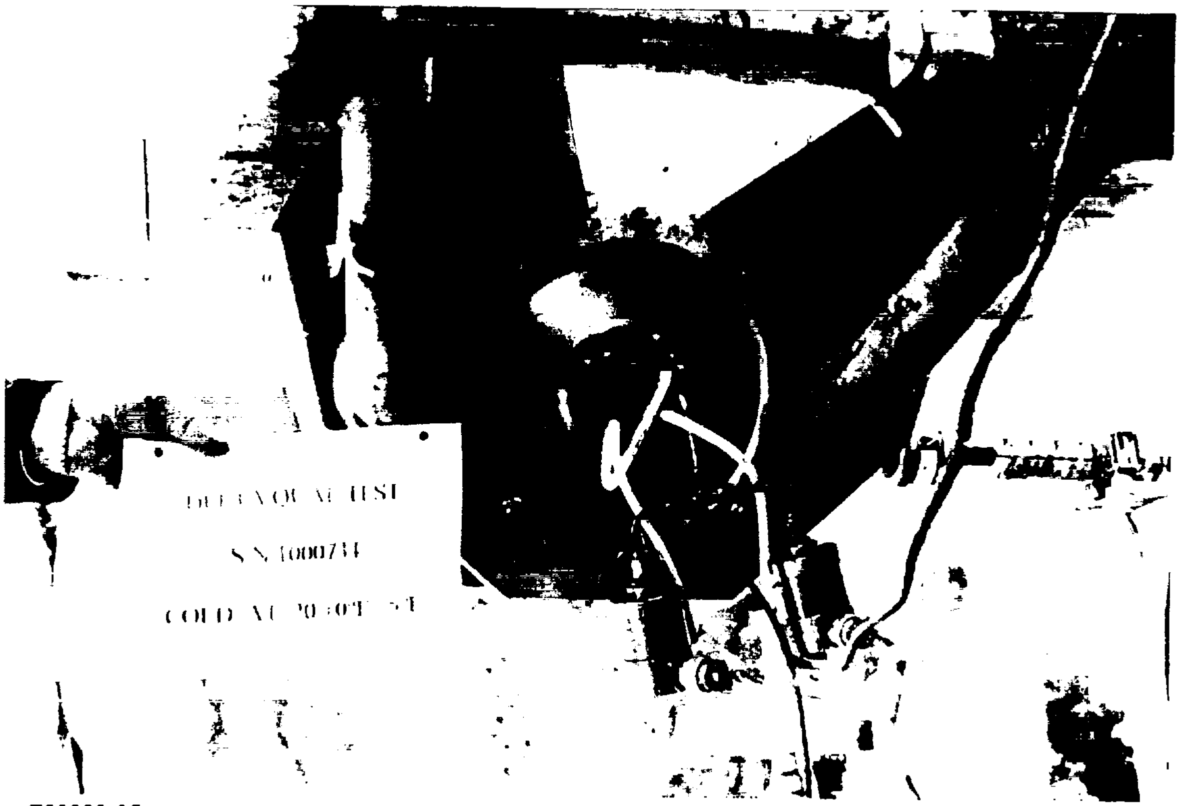


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Figure 6.1-4. Motor S/N 1000734 (22.2°F), Posttest Forward View

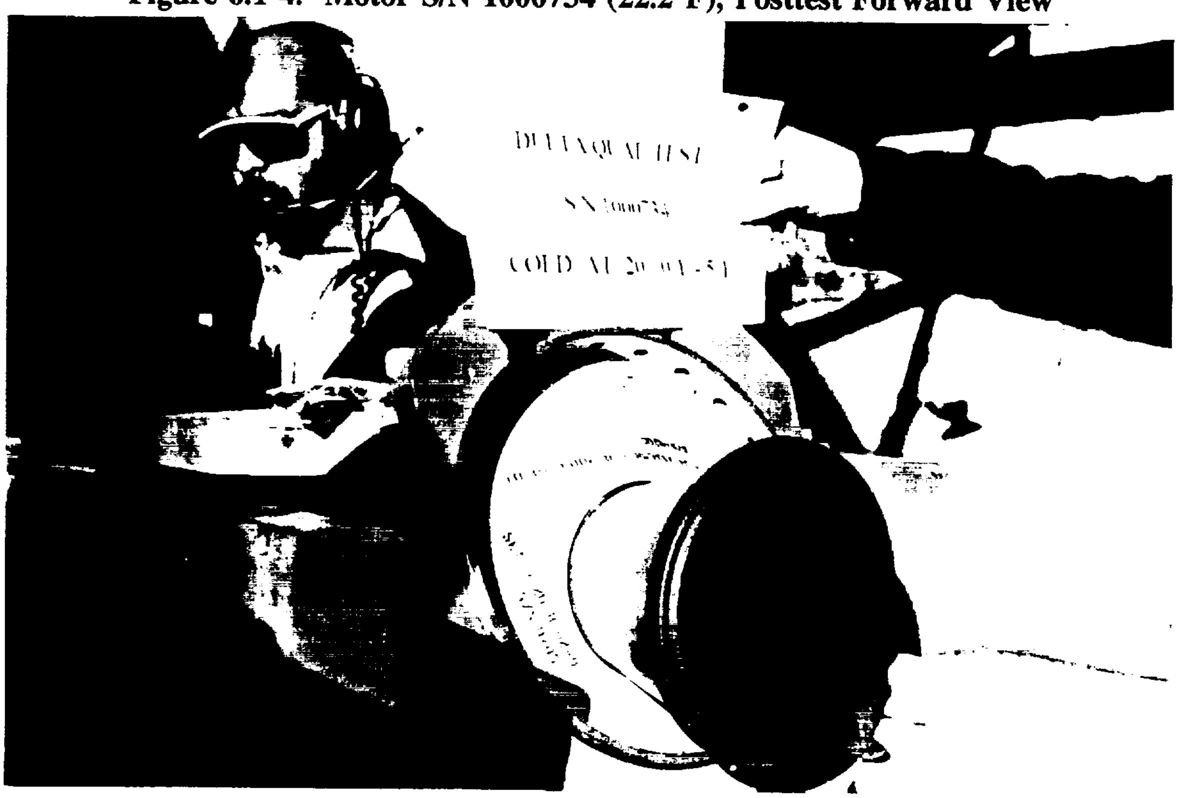

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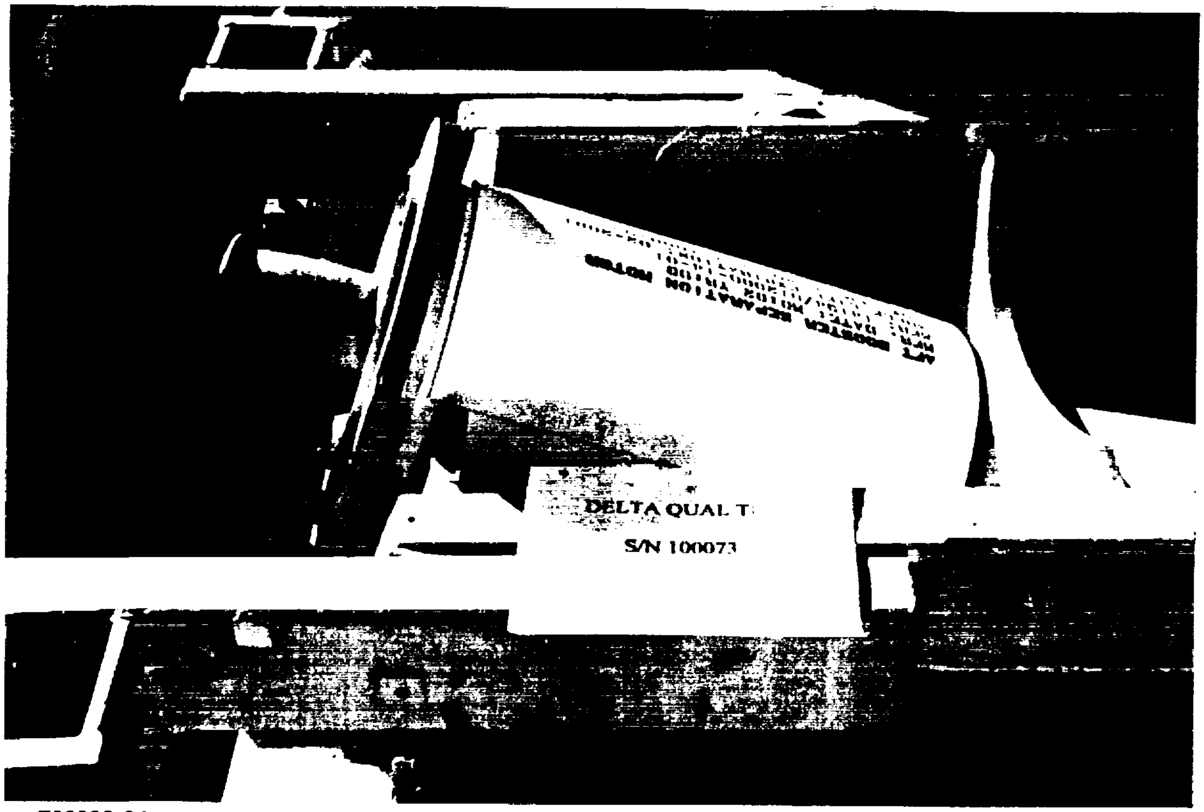
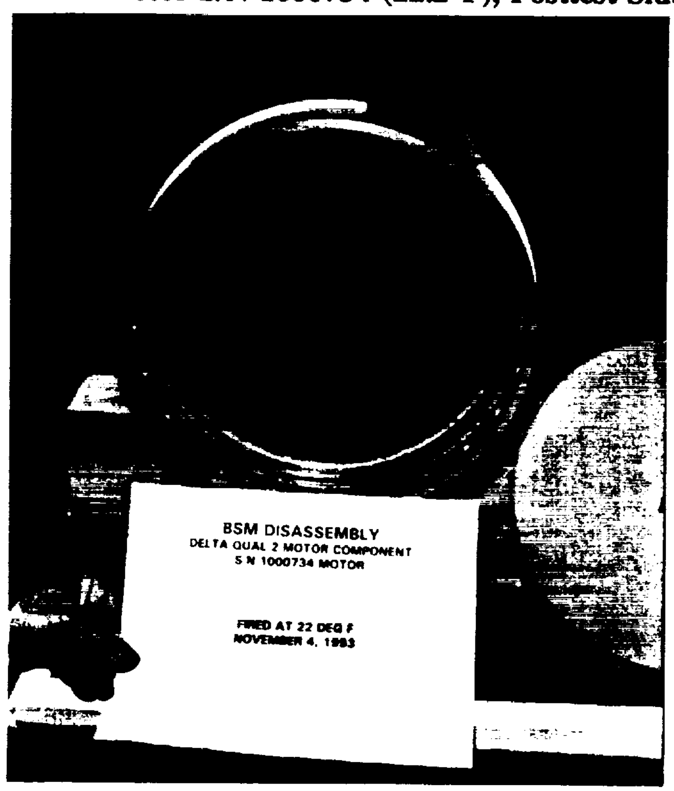
Figure 6.1-5. Motor S/N 1000734 (22.2°F), Posttest Aft View



C20933-24

Figure 6.1-6. Motor S/N 1000734 (22.2°F), Posttest Side View



C20941-3

Figure 6.1-7. Motor S/N 1000734 (22.2°F), Posttest Case Internal View

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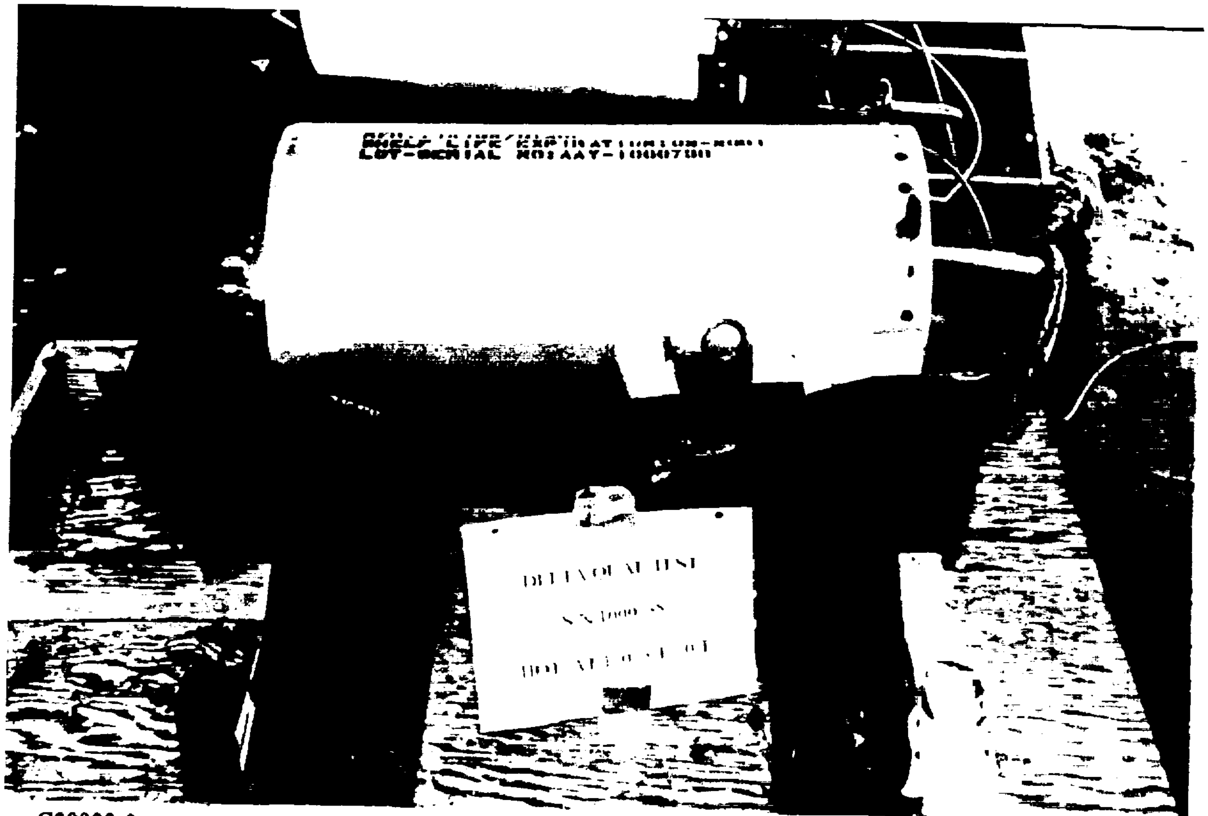
C20933-10

Figure 6.1-8. Motor S/N 1000738 (129.5°F), Pretest Forward View

C20933-16

Figure 6.1-9. Motor S/N 1000738 (129.5°F), Pretest Aft View



C20933-9

Figure 6.1-10. Motor S/N 1000738 (129.5°F), Pretest Side View

This motor was also found, in conjunction with the motor performance analyses discussed in Section 5, to have provided the proper test bed for assessing the enhancements addressed in subsections 6.3 through 6.8 of this report.

6.2 O-RING INSPECTIONS. As shown in figure 6.2-1, there are five sets of redundant O-rings at every component interface in the BSM where pressure integrity must be maintained. Each set of O-rings in both motors was subjected to inspection to determine if any of the enhancements incorporated into these motors had an adverse effect on the O-ring performance.

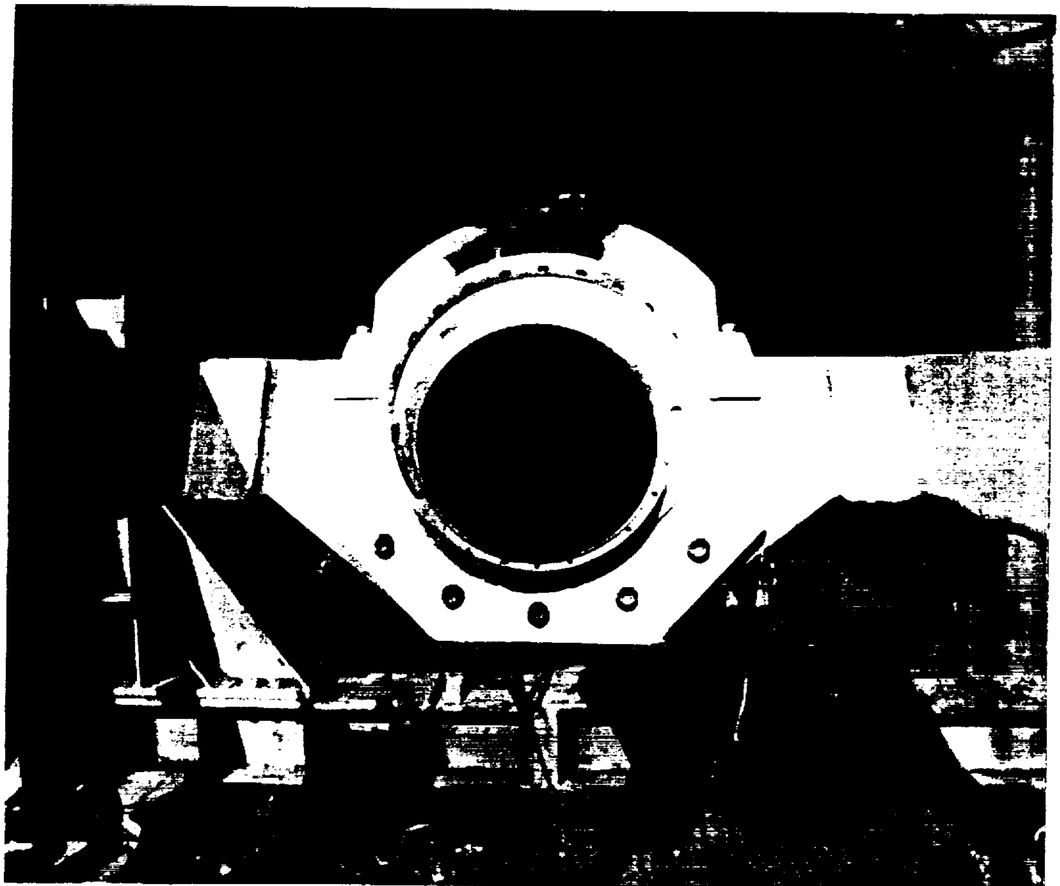
6.2.1 Success Criteria. The O-ring performance was judged against two criteria: (1) the 10SPC-0067 specification requirements and (2) by similarity comparison against the existing BSM O-ring performance database.

C20933-6

Figure 6.1-11. Motor S/N 1000738 (129.5°F), Posttest Forward View

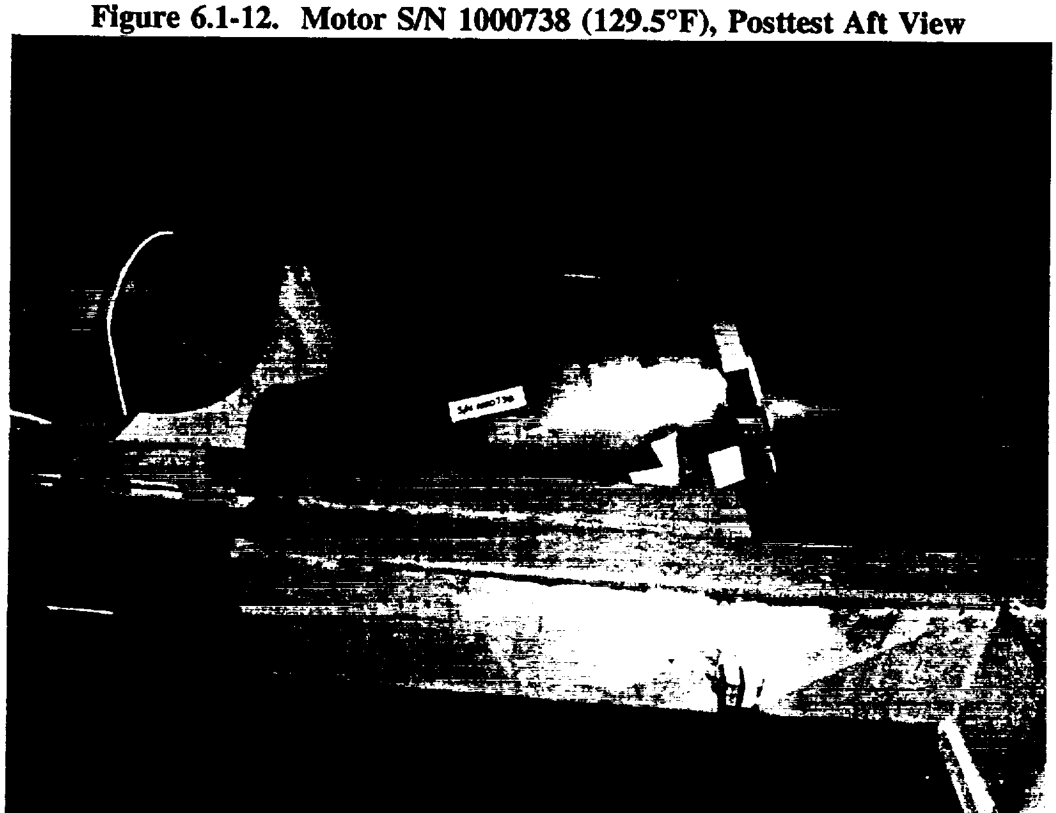
Specification Performance Requirement. Per 10SPC-0067, paragraph 3.2.7, "BSM Performance": "The BSM shall conform to the performance requirements specified herein after exposure to the natural and induced environments specified in paragraphs 3.2.9 and 3.2.7." These are the ballistic requirements of the motor. To meet these requirements, the O-rings must enable the motor to maintain pressure integrity during the entire time of its functioning (firing).

O-Ring Database Comparison. In addition, the O-ring performance was compared by similarity to the existing database developed from inspections of LATs, flown motors, and special ground test motors as discussed below. These comparisons were done to verify that the O-ring performance was consistent with the test conditions and with the database.



C20933-3

Figure 6.1-12. Motor S/N 1000738 (129.5°F), Posttest Aft View



C20933-5

Figure 6.1-13. Motor S/N 1000738 (129.5°F), Posttest Side View

C20933-17

Figure 6.1-14. Motor S/N 1000738 (129.5°F), Posttest Side View

6.2.2 Test Results. Posttest inspection of all O-rings showed that, as expected based on the available database, only the nozzle closure primary O-rings in the cavity directly charged by the combustion gases during the ignition transient to ensure proper seating and sealing of the O-ring experienced any erosion. A summary of the maximum erosion on the nozzle closure primary O-rings is provided below:

Motor S/N	Test Temperature °F	Ignition Time, sec	Maximum Erosion, in.	Comments
1000734	22.2	0.054	0.008	Char/erosion entire circumference except between 20 to 30°
1000738	129.5	0.034	0.023	Char/erosion entire circumference except between 130 to 150° and 200 to 210°

The clearance between the motor case O-ring sealing surface and the nozzle closure insulation OD and the forward nozzle closure lip when installed in a motor case intentionally form the small annular entrance area for the combustion gases to fill or "charge" the nozzle closure primary O-ring. This area is open for the 360° circumference, which allows the combustion gases to uniformly charge the O-ring and minimizes circumferential flow in the O-ring groove (see Reference 2).

C20933-1

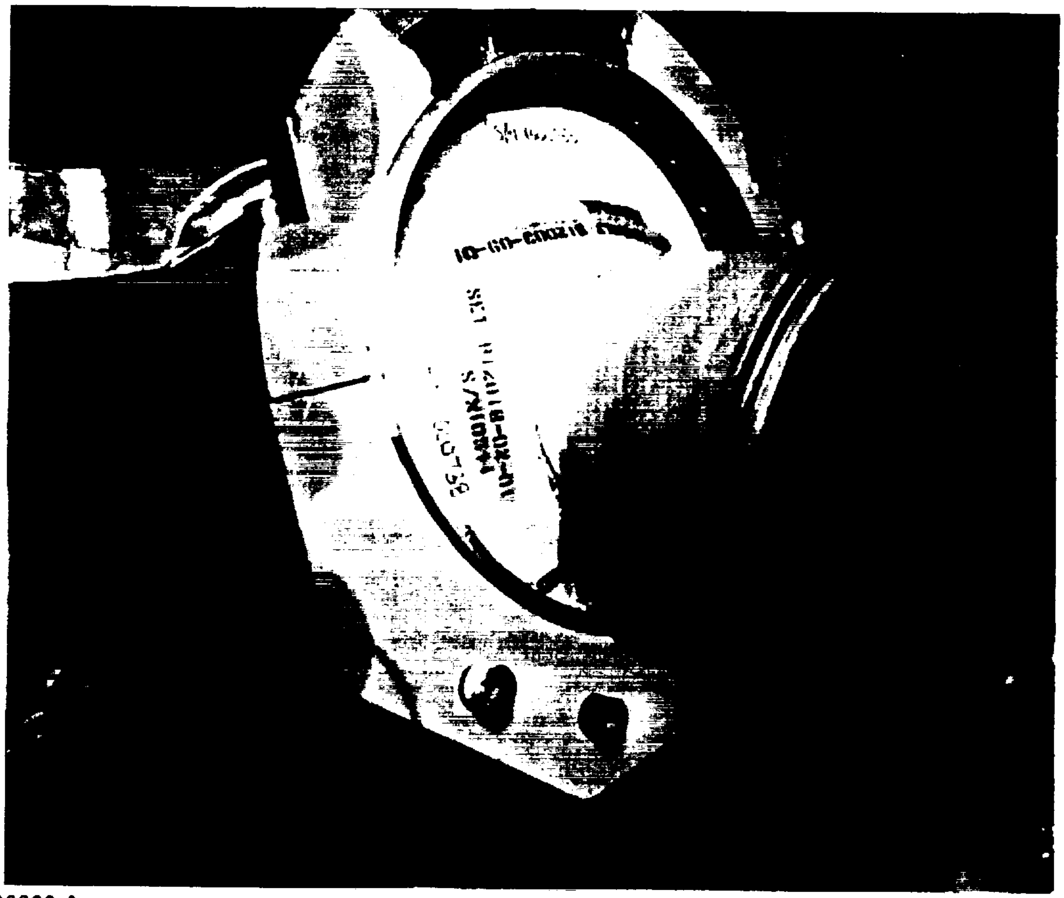
Figure 6.1-15. Motor S/N 1000738 (129.5°F), Posttest View of Nozzle/Closure Interface

Posttest examination of the primary O-rings confirms that the O-ring cavities were charged uniformly around the circumference, which is the desired approach. Otherwise, localized areas of high O-ring erosion are encountered.

The lack of variation in ablation around the circumference makes it difficult to determine the area of maximum ablation, but it appears to be at 15° aft looking forward (ALF) for motor S/N 1000734 and 80° for motor S/N 1000738 with 0° (TDC) in the direction of the nozzle cant (20° angle). This is consistent with the 1988 Delta Qualification motors (see Reference 8).

Review of the primary O-ring database presented in figure 6.2-2 shows that the erosion experienced on Delta Qualification motor S/N 1000738 appears to be higher than would be expected. In assessing the O-ring performance, however, one must recognize that Delta Qualification motor S/N 1000738 was intentionally static tested per customer direction at a higher temperature than normal (129.5°F vs 120°F). This in turn results in a shorter than normal ignition time (see figure 5.2-21). The shorter the ignition time, the quicker the O-ring cavity charging and the faster the gas flow into the O-ring cavity. The net result is an increase in the nominal O-ring erosion.

Even for this overtest condition, however, the O-ring erosion is consistent with the test condition and within the database.



C20933-2

Figure 6.1-16. Motor S/N 1000738 (129.5°F), Posttest View of Nozzle/Closure Interface

The amount of ablation seen here and in the Delta Qualification Program conducted in 1988 (see Reference 8) is less than 10% of the O-ring diameter and is within the design parameters.

Prior to the 1988 Delta Qualification program, motors had been successfully fired with up to 0.056 in. of ablation (see Reference 8). During the 1988 Delta Qualification Program there was one motor successfully fired without any primary O-rings (except for the pressure port since pressure data was being recorded for the motor firing), two motors successfully fired without any motor O-rings (except pressure port) and two motors successfully fired with large cuts in the O-rings. There was no thermal damage on any sealing areas in any of these tests.

Therefore, the performance of O-rings in these Delta Qualification motors is acceptable and consistent with the database. There are no abnormal or deleterious effects noted and there is no evidence of any effect of the enhancements on the O-ring performance.

6.3 VULCANIZED AFT CLOSURE INSULATION ENHANCEMENT. The present method of insulating the BSM aft closure is a very labor-intensive effort and is therefore high cost. Based on initial investigations by CSD in 1988, incorporation of a vulcanized insulation process offers the potential for enhanced producibility and improved component quality.

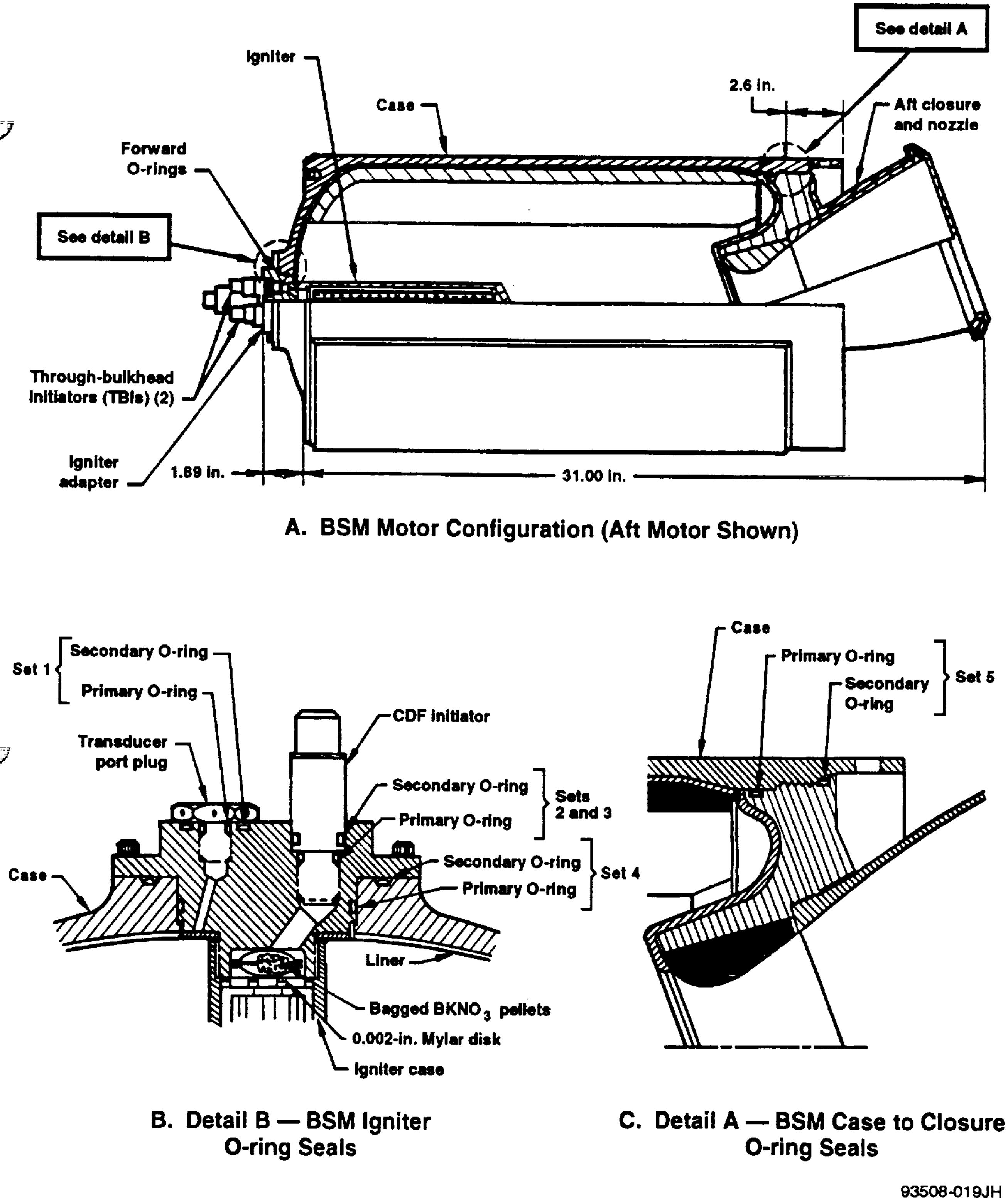
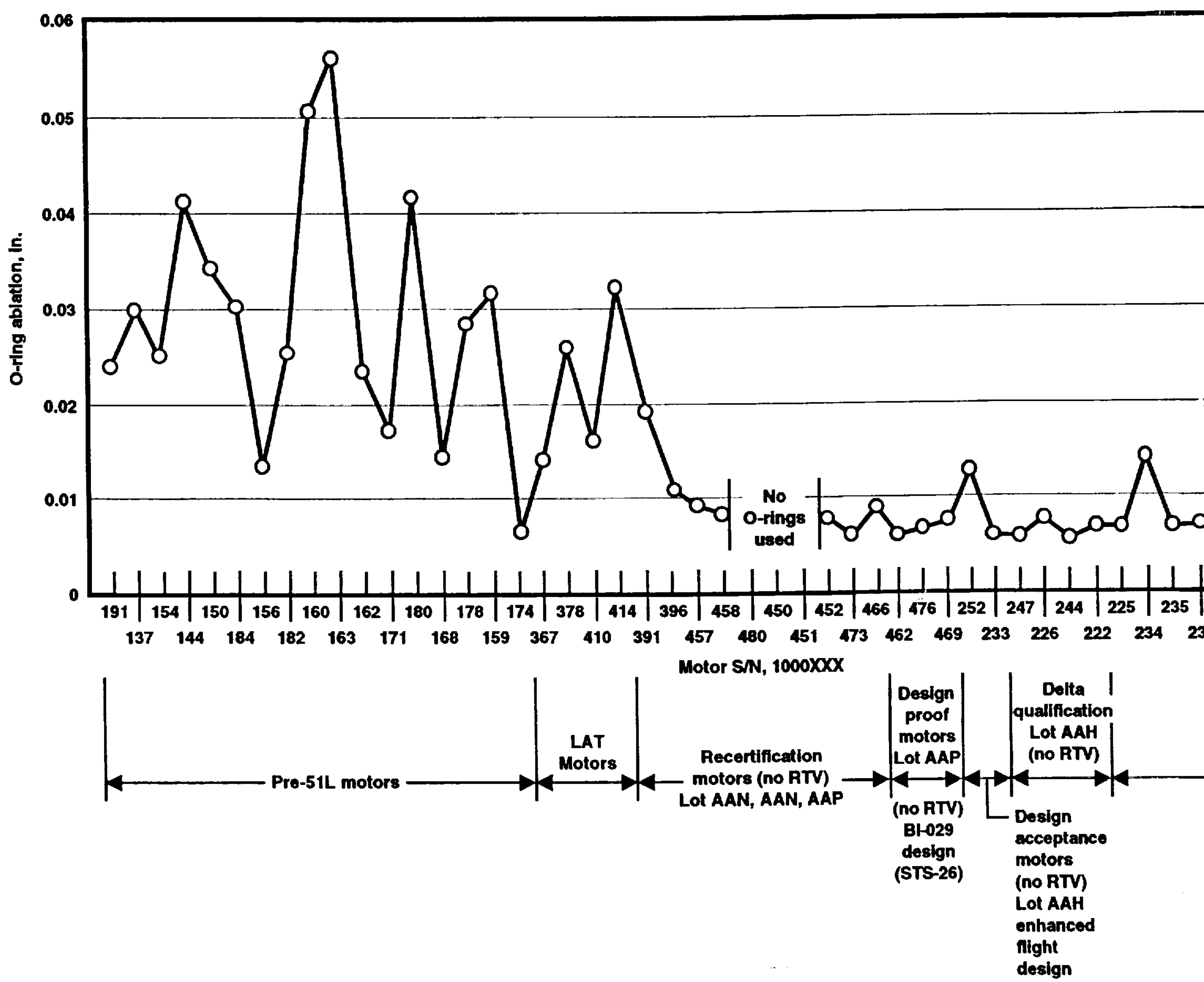


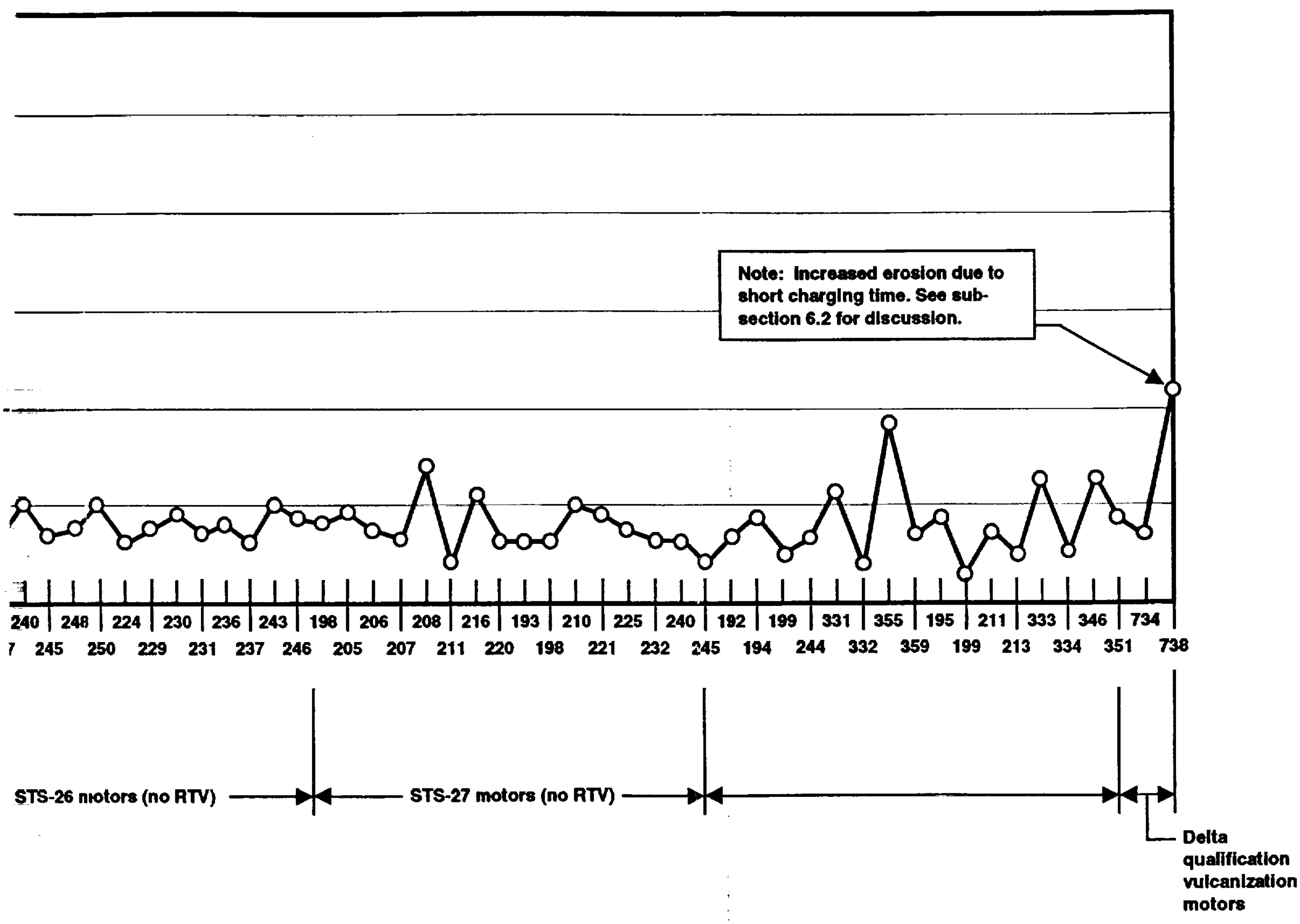
Figure 6.2-1. BSM Motor Configuration Details

6.3.1 TQM Initiative Description. The present method of bonding the aft closure insulator to the aft closure involves secondarily bonding the silica-filled NBR insulator to the aluminum closure using a two-part epoxy adhesive. The insulator is a molded part that is fully cured and then mated with the closure several weeks later.

FOLDOUT FRAME



FOLDOUT FRAME 2.



93508-001JH

Figure 6.2-2. Summary of BSM Aft Closure O-ring Ablation

Because of the complex shapes of the closure and the mating rubber insulator, there have been instances in which there is a significant mismatch between the insulator and closure resulting in "bondlines" as thick as 0.300 in. This "mismatch" of mating parts can result in significant rework, loss of production time, and increased costs.

A vulcanized insulator gives the advantage of providing a total match between the insulator and the closure with thin, high-strength bondlines, and virtually eliminates unbonds.

Vulcanization provides the potential for reducing the production cost of the closure by eliminating hardware rejections and the need for costly NDT of the insulated closure.

The TQM initiative included in the Delta Qualification motors was the replacement of the secondarily bonded aft closure insulator with the vulcanized aft closure insulator.

6.3.2 Success Criteria. Specification 10SPC-0067 requires that insulation prevent the metallic components from reaching temperatures that would degrade their mechanical properties, and perform that function with a factor-of-safety of 1.25 on thickness (reference paragraph 3.2.1.2.3.7, page 22).

The success criteria defined in Test Plan CSD-5597-93-1 (see Appendix C, Volume III) for the Delta Qualification 2 motors is: "Demonstrate ability to remain in place during static test and demonstrate ablative capabilities that show no more than one-half (90 mils) of the insulator to be eroded during the static test. Verification to be obtained through post-test 0°-180° dissection measurements of fired nozzle closure insulation with comparison to sectioned development vulcanized insulator thicknesses."

In addition to the Delta Qualification 2 aft closure insulation test data, CSD provided to USBI and MSFC, per direction, additional data for the following items:

- Insulator thickness measurements for the six vulcanized demonstration units CSD processed prior to fabrication of the vulcanized Delta Qualification units
- Thickness measurements for ten (10) existing insulators that are used in the present secondary bonding process
- Insulation thickness measurements for 10 fired LATs which used the secondary bonding method for the aft closure insulation.

This database provided the means for completing an analysis by similarity between the secondarily bonded and vulcanized insulators.

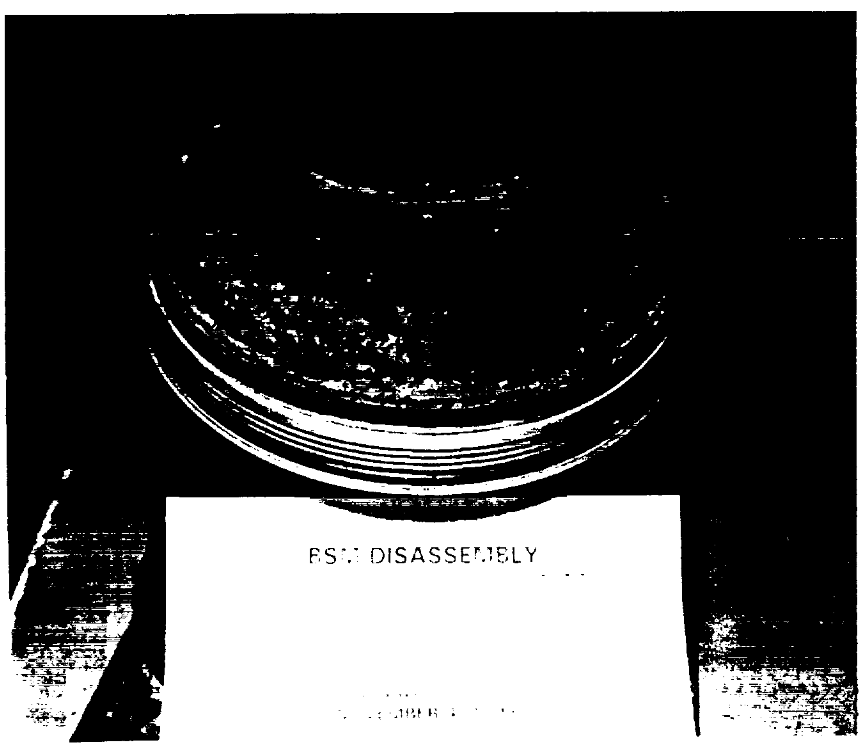
The results of both the comparison with the 10SPC-0067 requirements and analysis by similarity are provided below.

6.3.3 Test Results. As noted in subsection 6.3.2, the performance of the vulcanized insulator incorporated in the two Delta Qualification motors was assessed by (1) direct evaluation of the two insulators to the criteria defined in 10SPC-0067, (2) evaluation to the criteria of Test Plan

CSD-5597-93-1, and (3) by similarity comparison to a database developed from "as molded" secondarily bonded units, and the six vulcanized development units that were completed to optimize the vulcanization process prior to fabrication of the two Delta Qualification units. The values from the demonstration vulcanization peel panels (reference the interim report in Appendix L, Volume III, Book 2) were all greater than 80 pli. This gives a factor-of-safety greater than three (3) for the minimum acceptance value of 25 pli and a margin-of-safety greater than +4.8 based on a design value of 9.84 pli required. The margin of safety is calculated as (80/9.84 x 1.4) - 1 = +4.8, where 1.4 = design factor of safety.

Following static testing, the motors were transported to Station 0485, where the nozzle closures were removed. USBI, NASA and CSD were in attendance for the disassembly inspection.

Both closures were in excellent condition. Visual inspection showed the insulators to be bonded and fully attached for the full 360° circumference (see figures 6.3-1 through 6.3-8). There were no areas of abnormal ablation. Small variations in ablation were noted which aligned with the rays in the motor grain. This phenomenon is also consistent with the performance for the secondarily bonded insulators.



C20941-17

Figure 6.3-1. Vulcanized Insulated Aft Closure, Motor S/N 1000734 (22.2°F), Posttest

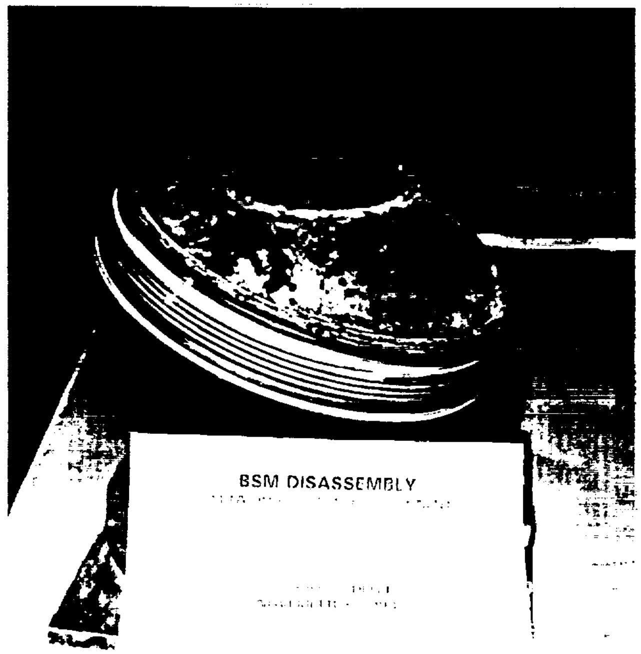


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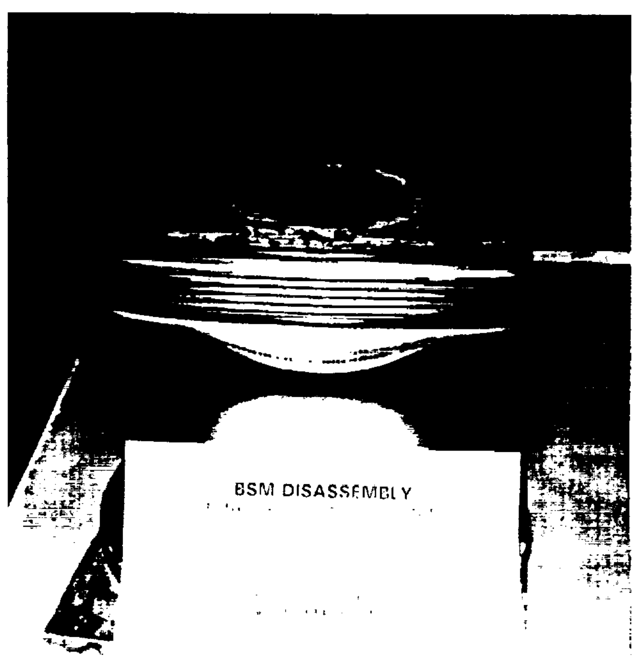
Figure 6.3-2. Vulcanized Insulated Aft Closure, Motor S/N 1000734 (22.2°F), Posttest



C20941-19

Figure 6.3-3. Vulcanized Insulated Aft Closure, Motor S/N 1000734 (22.2°F), Posttest

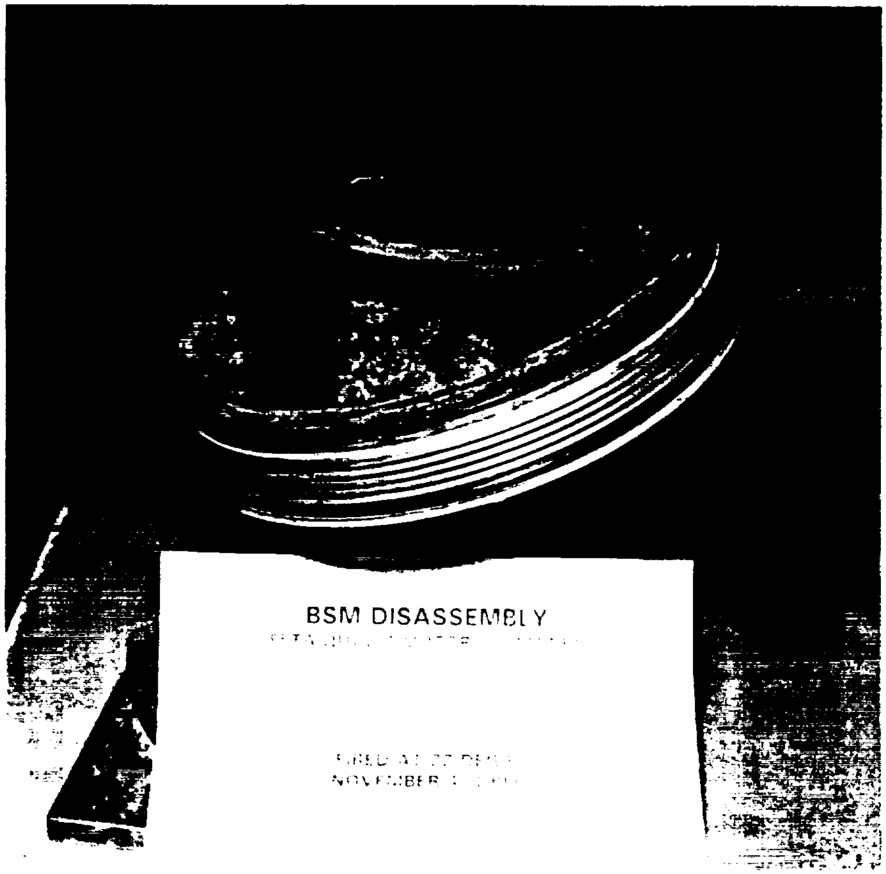


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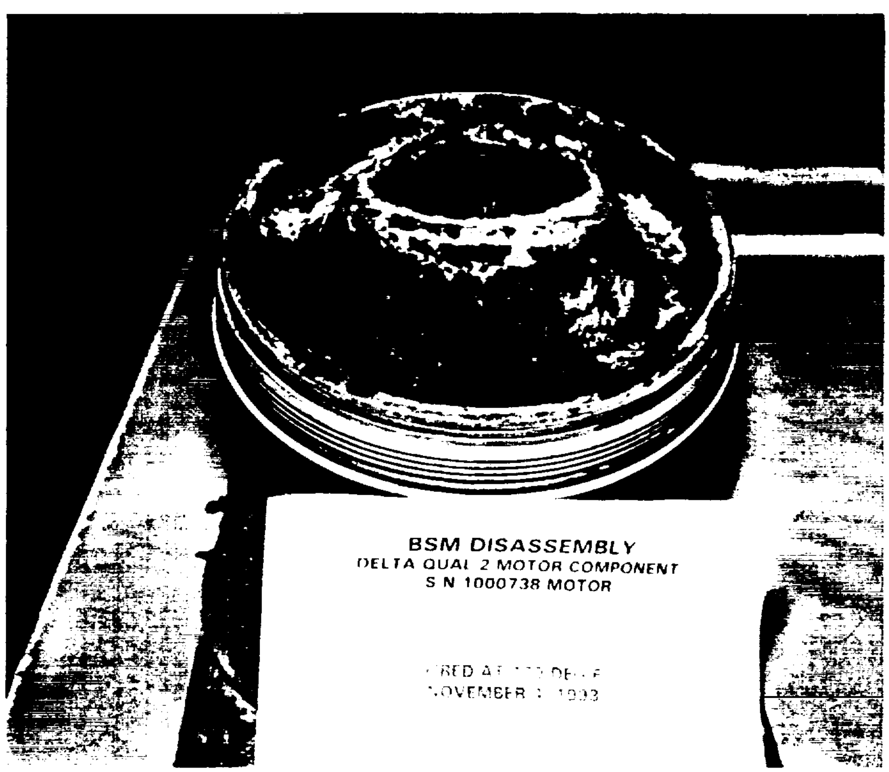
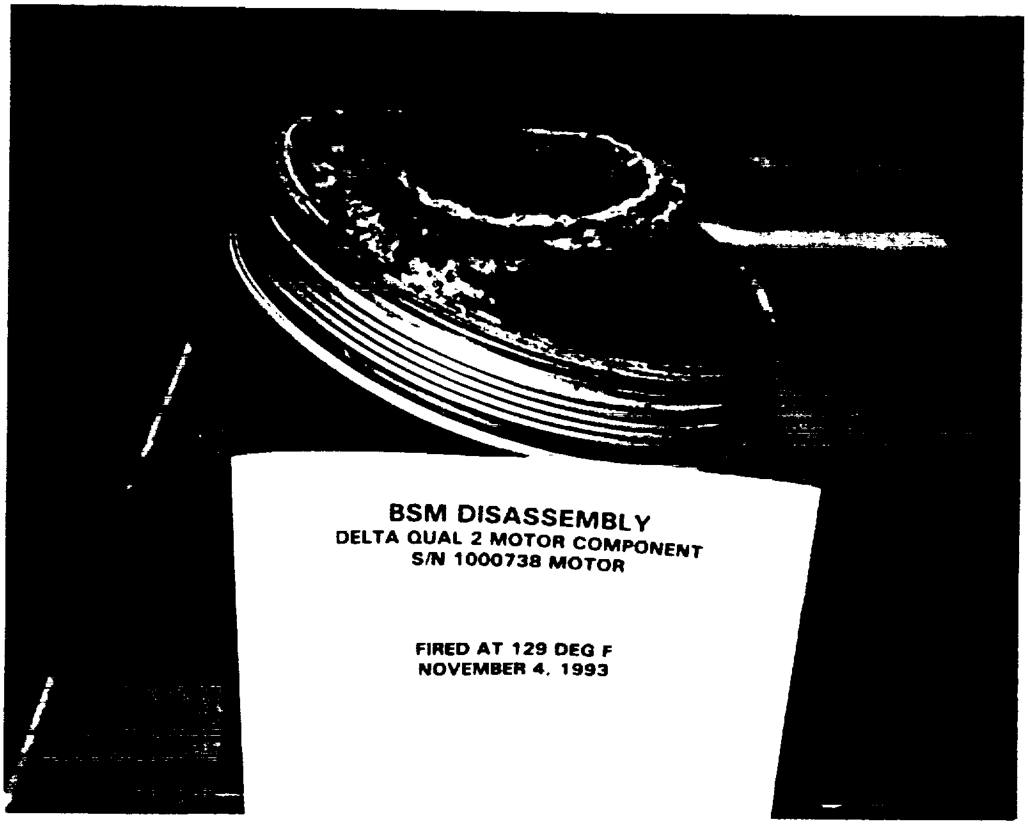
Figure 6.3-4. Vulcanized Insulated Aft Closure, Motor S/N 1000734 (22.2°F), Posttest



C20941-7

Figure 6.3-5. Vulcanized Insulated Aft Closure, Motor S/N 1000738 (129.5°F), Posttest



C20941-8

Figure 6.3-6. Vulcanized Insulated Aft Closure, Motor S/N 1000738 (129.5°F), Posttest

C20941-9

Figure 6.3-7. Vulcanized Insulated Aft Closure, Motor S/N 1000738 (129.5°F), Posttest

C20941-10

Figure 6.3-8. Vulcanized Insulated Aft Closure, Motor S/N 1000738 (129.5°F), Posttest

Review of the high speed movie films (i.e., 1000 fps) verified the absence of exhaust debris.

After removal of the char layer by wiping with a cheesecloth, the surfaces of the insulators were heat affected as expected and were smooth. In particular, the areas where the ridge on the insulators had been removed by abrasion prior to final assembly (reference NCRs D12391 and D12394 in Appendix J, Volume III, Book 2) were examined to determine if any uneven ablation had occurred. The ablation was very even across that repaired area on both insulated closures.

The OD RTV-102 repaired area on motor S/N 1000738 exhibited no unbonds after the test and ablated/eroded at the same rate as the surrounding silica-filled NBR rubber insulator. There was a "separation" approximately 1¼ in. long at the same azimuth as the RTV repair, but on the upper surface. The "separation" has sharp edges and appeared to have a depth of approximately 0.040 to 0.050 in. for the middle half of its length. The "separation" appears to have been induced prior to static test and to have been caused by a sharp instrument like an x-acto knife. Due to the stiffness of the insulation, however, the separation did not open during motor operation as evidenced by the lack of erosion on the edges. This provides additional, though unintentional, evidence of the high integrity of the insulated aft closure design.

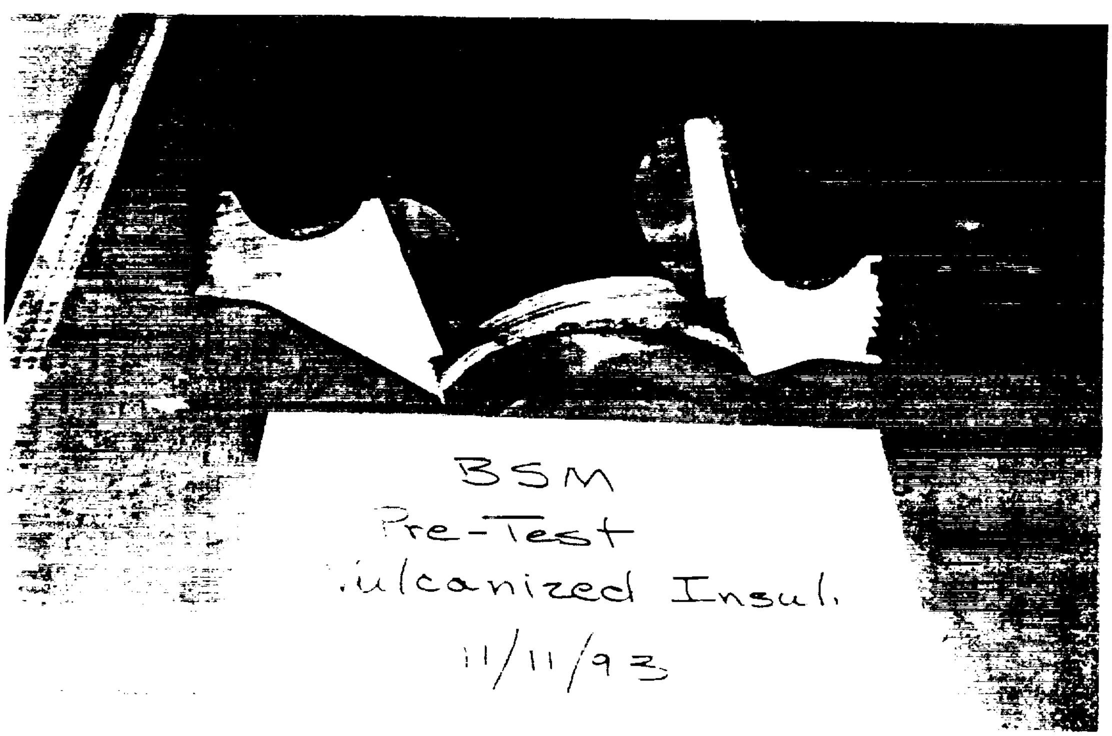
The pretest ultrasonic and tap test inspections showed no insulator/closure unbonds on either closure. The post-static test ultrasonic and tap tests showed no unbonds either in the areas that could be inspected. Due to the slightly ablated surface irregularities on each insulated surface, there were approximately 40 in.^{2} of area that could not be ultrasonically inspected. Manual loading of these OD areas supported the conclusion that no unbonds were created by the motor firings. In addition, these areas were inspected visually after the insulators were dissected (see discussion that follows) and were found to have no unbonds.

The nozzle closures from the Delta Qualification 2 motors were sectioned and remaining insulation thicknesses measured to determine compliance with the 1.25 factor-of-safety requirement of the 10SPC-0067 specification.

Visual Inspection of Sectioned Insulated Closures. This discussion addresses the results of the visual inspection of the Delta Qualification sectioned insulated aft closures and compares their performance by similarity to the performance of the presently used secondarily bonded insulated aft closures. The subsection that follows addresses the results of the specific thickness measurements taken in assessing the performance of the vulcanized aft closures.

Figures 6.3-9 through 6.3.11 provide views of a sectioned, unfired, vulcanized insulated aft closure that was fabricated as part of the vulcanization demonstrations which preceded the fabrication of the Delta Qualification units. Based on NDT of six demonstration units and the Delta Qualification units, which showed the total absence of any unbonds, the characteristics of the sectioned closure shown in figures 6.3-9 through 6.3-11 are typical of vulcanized units.

As noted in all three views, the vulcanized insulator does not exhibit any unbonds and provides for a very high strength, thin bondline throughout the interface with the aft closure.



C20941-32

Figure 6.3-9. Sectioned, Unfired (Demonstration Unit), Vulcanized Insulated Aft Closure

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Figure 6.3-10. Closeup of Unfired (Demonstration Unit), Sectioned, Vulcanized Insulated Aft Closure

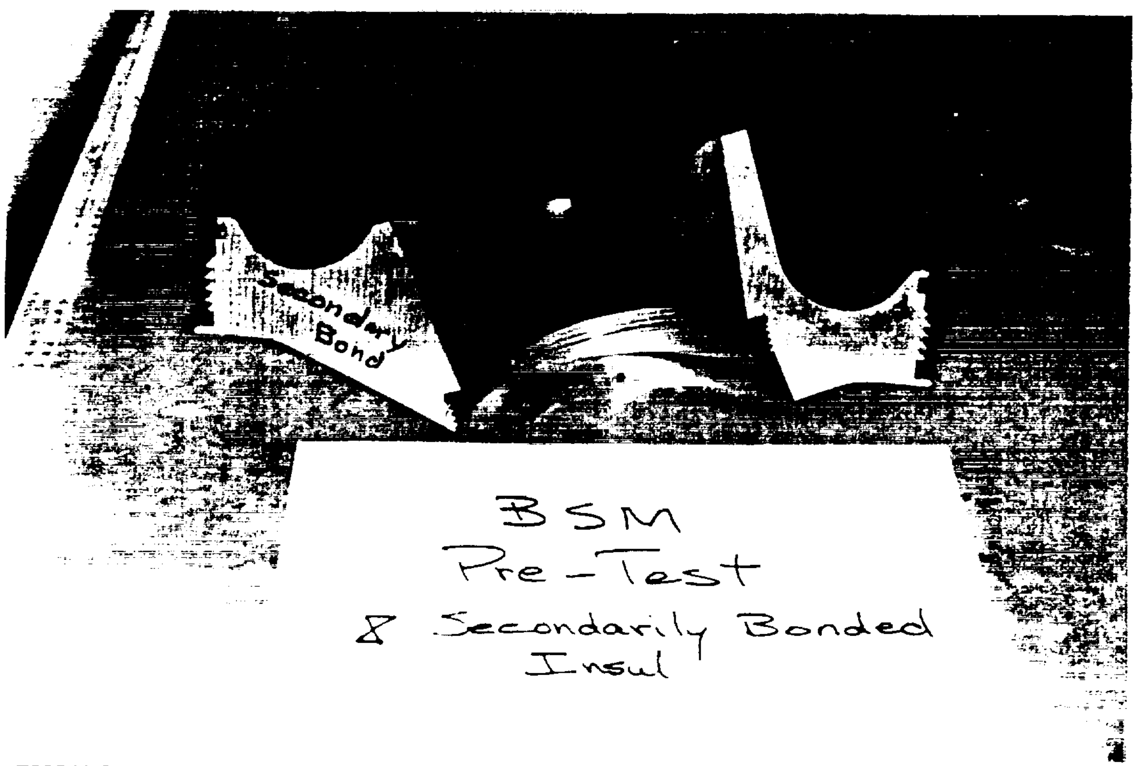
C20941-35

Figure 6.3-11. Closeup of Unfired (Demonstration Unit), Sectioned, Vulcanized Insulated Aft Closure

By comparison, figures 6.3-12 through 6.3-14 show the same views for a sectioned, unfired, secondarily bonded insulated aft closure. The unbond shown on the closure right hand face in figure 6.3-12 and shown in closeup in Figure 6.3-13 is typical of the secondarily bonded insulators. The bondline thickness variation as a function of location is also evident in the three sets of photographs.

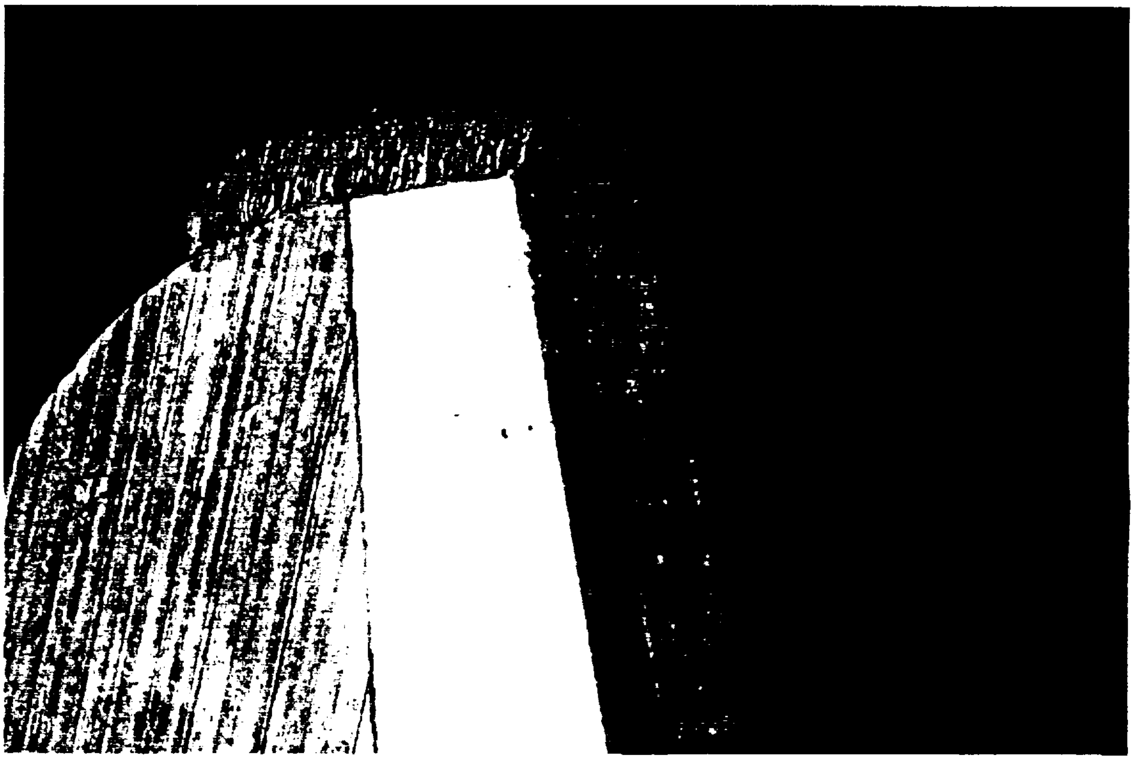
Although the bondline variations associated with the secondarily bonded insulator do not provide a technical compromise to the performance of the BSM, it does create an unnecessary, labor-intensive effort which can be greatly reduced by incorporating a vulcanization process.

The bondline variations noted with the secondarily bonded insulator are a direct result of bonding a fully cured, relatively inflexible insulator to a closure, both having very complex shapes. Slight variations in either or both components results in a mismatch which can result in a need to rework the insulated closure. On the other hand, vulcanization of a partially cured insulator to the aft closure allows the insulator to conform directly to the aft closure contour during the final insulator curing cycle, thus eliminating any "mismatch" and providing a consistently thin and strong bondline.



C20941-36

Figure 6.3-12. Sectioned, Unfired (Demonstration Unit), Secondarily Bonded Insulated Aft Closure



C20941-37

Figure 6.3-13. Closeup of Unfired (Demonstration Unit), Sectioned, Secondarily Bonded Insulated Aft Closure

C20941-38

Figure 6.3-14. Closeup of Unfired (Demonstration Unit), Sectioned, Secondarily Bonded Insulated Aft Closure

Figures 6.3-15 through 6.3-17 and figures 6.3-18 through 6.3-20 show sectioned views of the fired, vulcanized insulated aft closures from Delta Qualification motors S/Ns 1000734 and 1000738, respectively. As noted in all of the photographs, both vulcanized insulators remained totally intact with no unbonds detected. Posttest NDT further verified the absence of unbonds throughout both insulated closures.

As expected, virgin rubber material was found at all locations in the post-fired insulators, verifying proper closure protection. Consistent with this finding was the total absence of any localized heating or melting of the closure itself.

Although the cutting of the fired closures did impart some localized chipping of the graphite and spreading of the aluminum from the aft closure, this "damage" is readily visible in the photographs and therefore can be determined to be an artifact of the sectioning process and not of the motor firings themselves. In addition, the insulator thickness measurements discussed in the following subsection reflect the measurements taken after the "closure metal spreading from the dissection" was cleaned away, thereby giving a true evaluation of the post-fired insulation thicknesses.

Figures 6.3-21 through 6.3-23 show similar posttest photographs of a sectioned, fired, secondarily bonded insulator. As with the vulcanized units, the posttest condition of the secondarily bonded insulated aft closure is in excellent condition. Although these units do exhibit pretest unbonds (see discussion above), there has been no evidence that these unbonds are altered by a motor

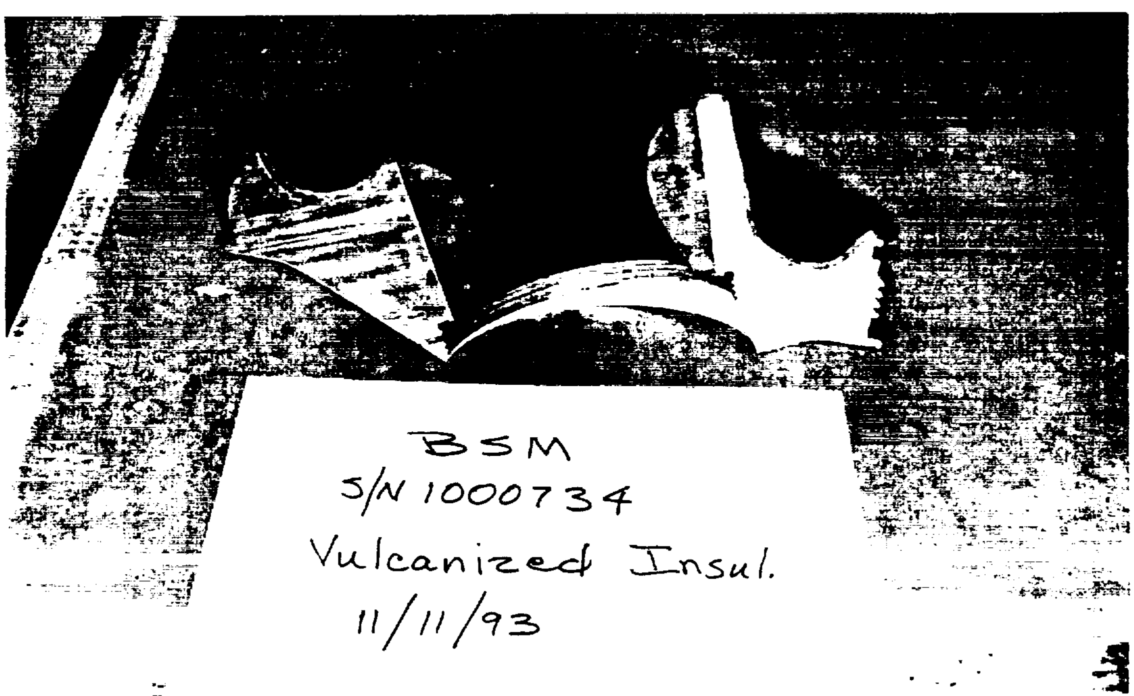


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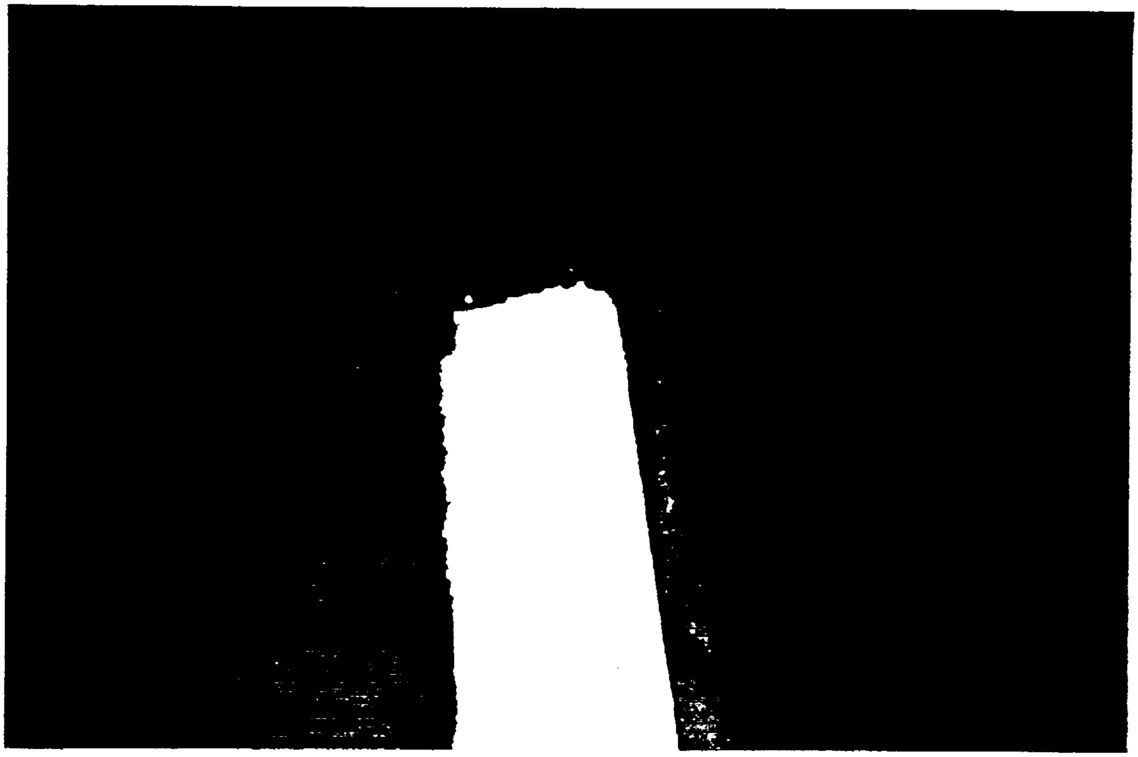
Figure 6.3-15. Sectioned, Fired, Vulcanized Insulated Aft Closure, Motor S/N 1000734 (22.2°F)



C20941-27

Figure 6.3-16. Closeup of Fired, Sectioned, Vulcanized Insulated Aft Closure, Motor S/N 1000734 (22.2°F)

C20941-28

Figure 6.3-17. Closeup of Fired, Sectioned, Vulcanized Insulated Aft Closure, Motor S/N 1000734 (22.2°F)

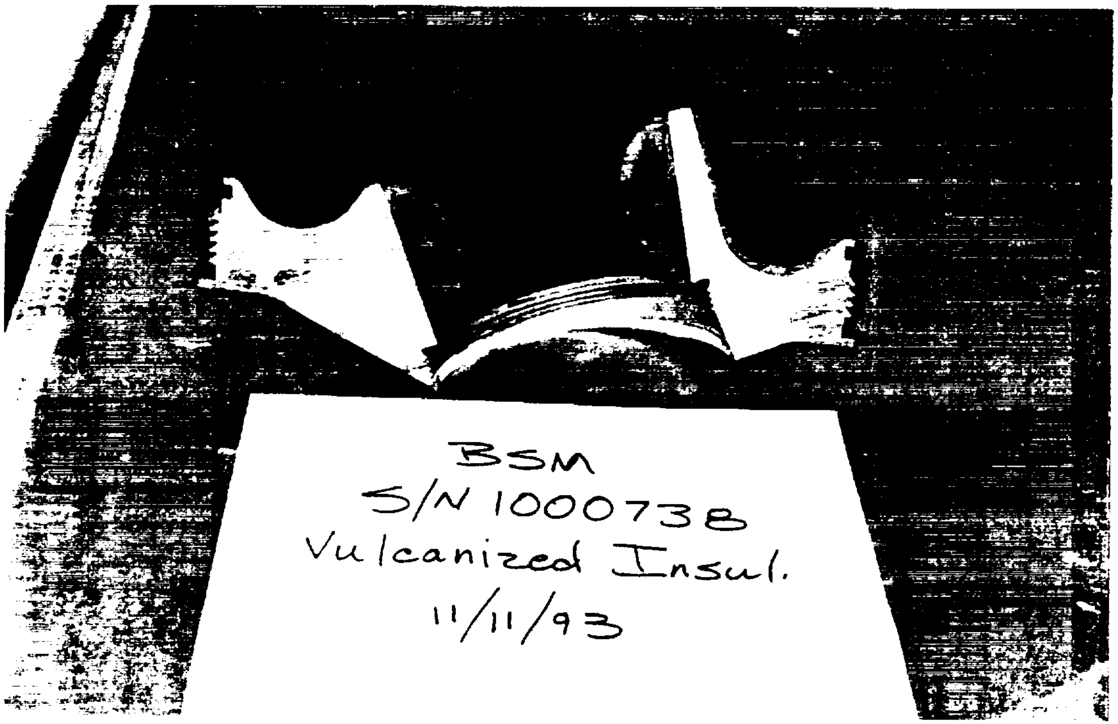


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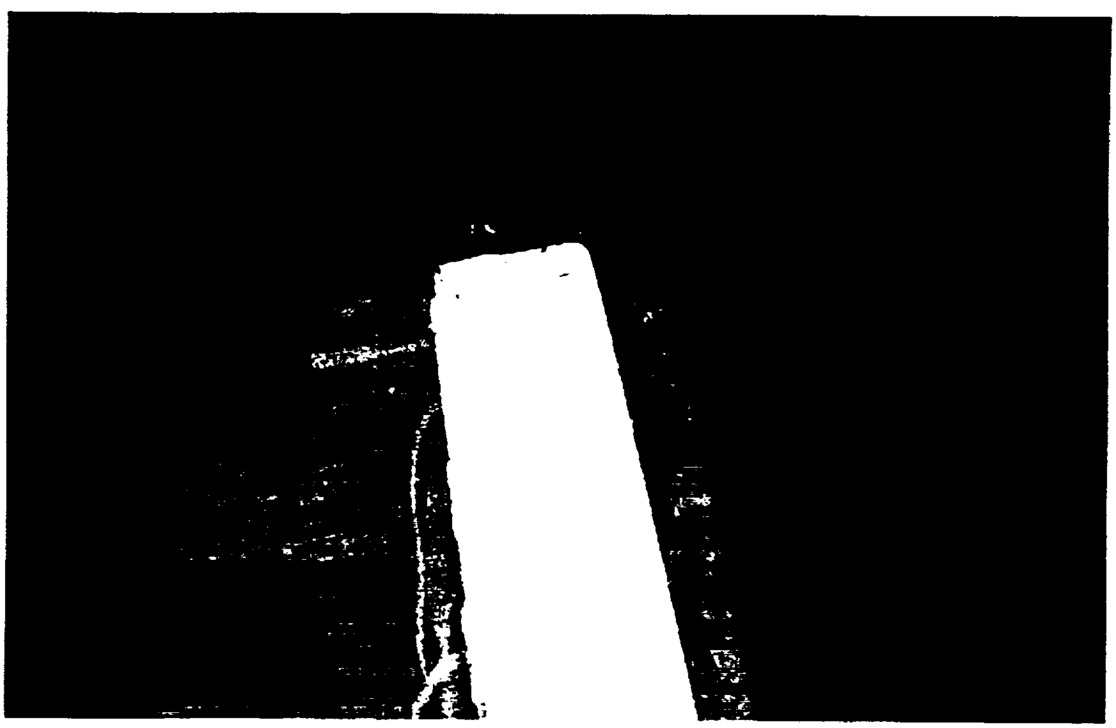
Figure 6.3-18. Sectioned, Fired, Vulcanized Insulated Aft Closure, Motor S/N 1000738 (129.5°F)

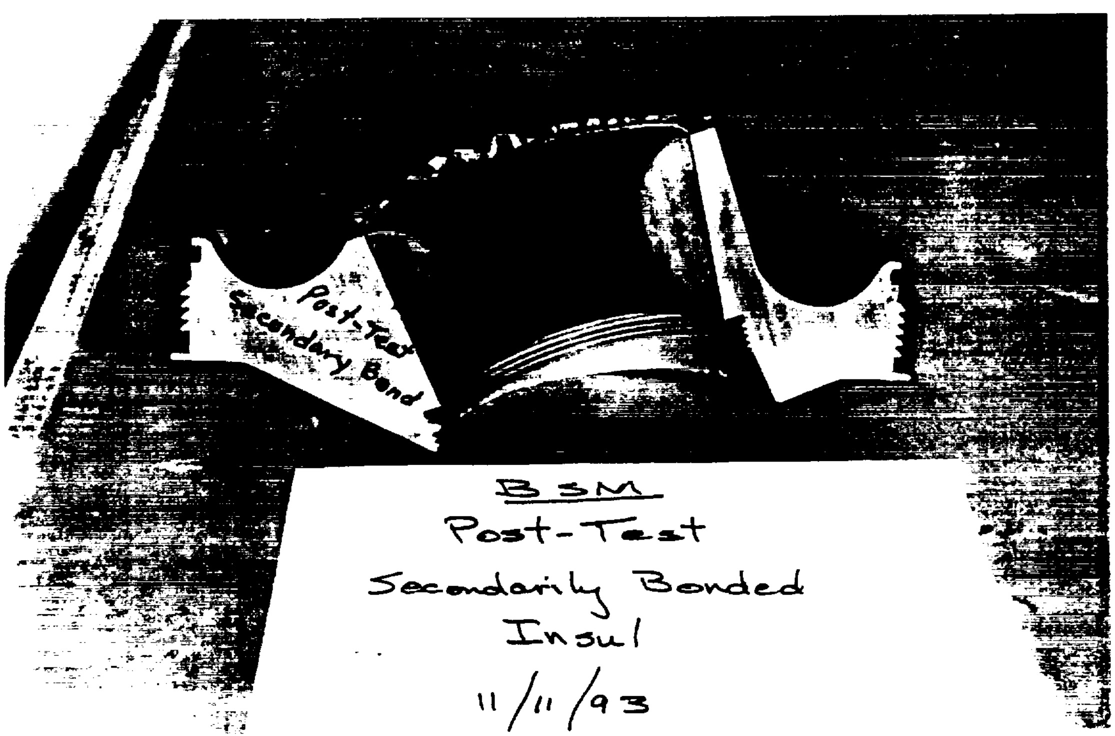


C20941-30

Figure 6.3-19. Closeup of Fired, Sectioned, Vulcanized Insulated Aft Closure, Motor S/N 1000738 (129.5°F)

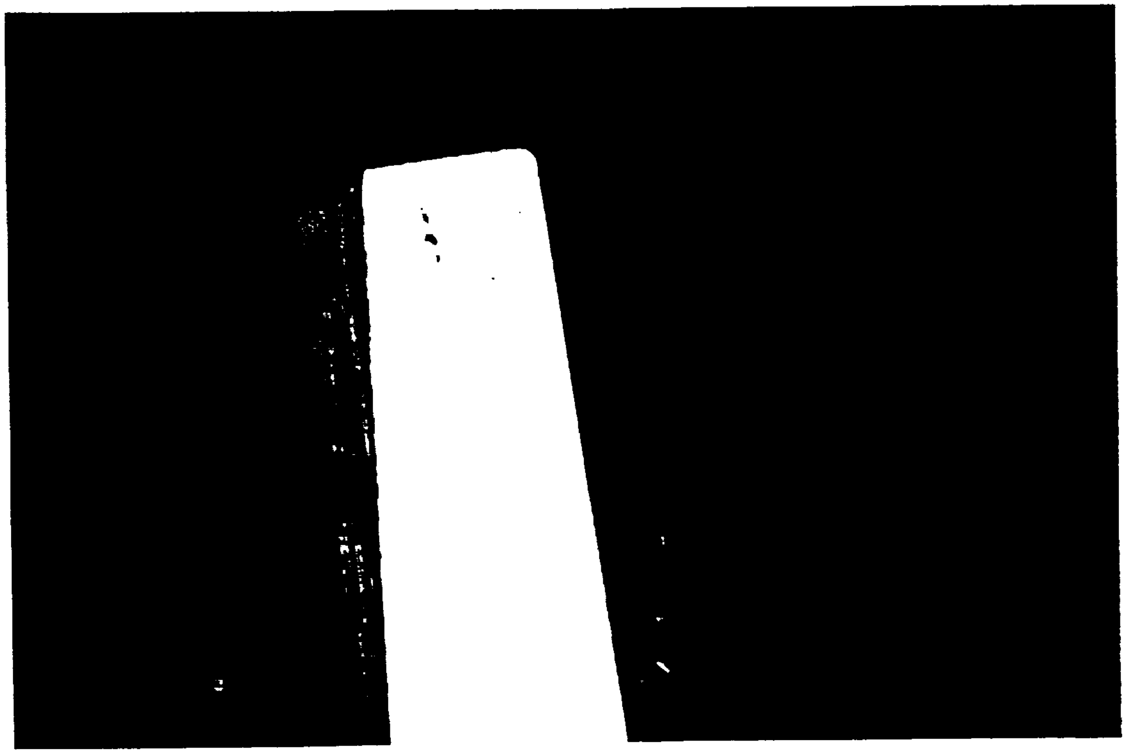
C20941-31

Figure 6.3-20. Closeup of Fired, Sectioned, Vulcanized Insulated Aft Closure, Motor S/N 1000738 (129.5°F)



C20941-39

Figure 6.3-21. Sectioned, Fired, Secondarily Bonded Insulated Aft Closure



C20941-40

Figure 6.3-22. Closeup of Fired, Sectioned, Secondarily Bonded Insulated Aft Closure

C20941-41

Figure 6.3-23. Closeup of Fired, Sectioned, Secondarily Bonded Insulated Aft Closure firing. The lack of change in the unbonds is to be expected since, as with the vulcanized units, there is virgin material remaining after firing for the secondarily bonded units, again demonstrating the low temperature which penetrates the insulator, even after post-fire soakout.

The posttest visual inspection of the sectioned vulcanized aft closures shows them to be in excellent condition with no anomalies noted. The lack of unbonds both prior to and after firing further verifies their preference over secondarily bonded units from a producibility viewpoint. Both insulators provide, however, comparable and acceptable performance with respect to their function of protecting the aft closure during motor operation and post-firing soakout. The vulcanization process provides a potential producibility advantage over the secondarily bonded insulators.

Thickness Measurements of Sectioned Insulated Closures. Figure 6.3-24 summarizes the data obtained from the vulcanized insulator thickness measurements and evaluates the performance of the vulcanized insulator by similarity to the performance of the secondarily bonded insulators. The definition of the measurement stations (i.e., 1, 1A, 2, etc.) is shown in figure 6.3-25. All of the thickness measurements reported in figure 6.3-24 were taken by sectioning either the insulator itself if it was not bonded to an aft closure or by sectioning an insulated aft closure. This technique allowed the taking of most accurate and direct measurement of the insulators.

Figure 6.3-24(A) presents a listing of pretest thickness measurements of a series of vulcanized insulators which were fabricated prior to the Delta Qualification units. These seven vulcanized insulators were manufactured as part of the proofing of the vulcanization process leading to the Delta Qualification testing. These measurements were taken from dissected insulated aft closures.

Figure 6.3-24(C) shows the same measurements for a series of ten fully cured insulators which are used for the present secondary bonding method of aft closure insulation. These measurements were taken by dissecting insulators that were not yet bonded to aft closures.

Figure 6.3-24(F) provides a graphical presentation of the data averages from 6.3-24(A) and 6.3-24(C). This illustrates that the pretest insulator thicknesses for the fully cured and vulcanized insulators are comparable. This is to be expected since both parts are made from the same mold. Since, however, it is known that the fully cured insulators do not provide a close mating to the aft closure but that the vulcanized units do, some variation in thickness measurements between the two "designs" is to be expected due to the effects of the final vulcanization process in "fitting" the insulator to the aft closure.

Figure 6.3-24(B) provides the posttest thickness measurements for the two Delta Qualification motors. Similarly, figure 6.3-24(D) provides posttest measurements for secondarily bonded insulators from a series of static test motors. Both sets of measurements were taken by dissecting the fired insulated aft closures and taking direct measurements of the insulation thicknesses at the six locations shown in figure 6.3-25.

Figure 6.3-24(E) shows the composite plot of both sets of posttest insulator thickness measurements. Figure 6.3-24(F) shows a comparison of the average of the posttest data for both insulator types. As with the pretest data shown on the same plot, the posttest insulator thicknesses for both types of insulators are judged to be comparable.

FOLDOUT FRAME 1.

Designation	Measurement Station					
	1	1A	2	3	4	5
Vulcanized Demo 1	0.235	0.231	0.191	0.186	0.172	0.231
Vulcanized Demo 2	0.251	0.261	0.198	0.222	0.201	0.259
Vulcanized Demo 3	0.236	0.228	0.181	0.201	0.201	0.231
Vulcanized Demo 4	0.220	0.235	0.191	0.172	0.181	0.233
Vulcanized Demo 5	0.242	0.236	0.199	0.206	0.174	0.223
Vulcanized Demo 6	0.230	0.213	0.188	0.198	0.168	0.224
Early vulcanization	0.230	0.214	0.190	0.200	0.183	0.220
Average	0.236	0.234	0.190	0.198	0.183	0.232
Standard deviation	0.011	0.016	0.008	0.017	0.015	0.014

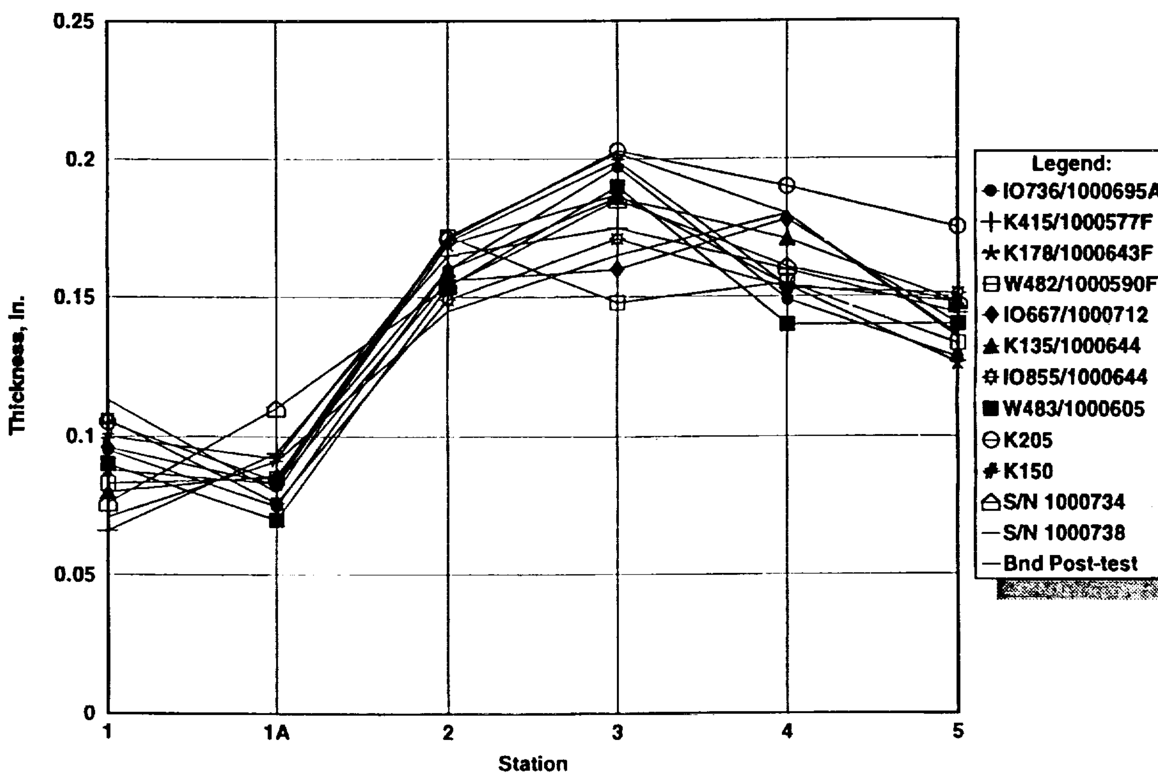
A. Pretest Vulcanized Insulator Thickness, in.

Designation	Measurement Station					
	1	1A	2	3	4	5
Delta qual motor S/N 1000734	0.076	0.110	0.154	0.185	0.161	0.148
Delta qual motor S/N 1000738	0.071	0.091	0.145	0.165	0.180	0.135

B. Posttest Vulcanized Insulator Thickness, in.

Designation	1	1
MFGA # 92136/1	0.224	0.
MFGA # 92136/2	0.221	0.
MFGA # 92139/1	0.230	0.
MFGA # 92139/2	0.228	0.
MFGA # 92140/1	0.221	0.
MFGA # 92140/2	0.225	0.
MFGA # 92140/3	0.220	0.
MFGA # 92141/1	0.231	0.
MFGA # 92141/2	0.230	0.
MFGA # 92141/3	0.228	0.
Average	0.226	0.
Standard deviation	0.004	0.

C. Pretest Secondarily Bo



E. Posttest Thickness Measurement Comparisons, Vulcanized and Secondarily Bonded

FOLDOUT FRAME 2.

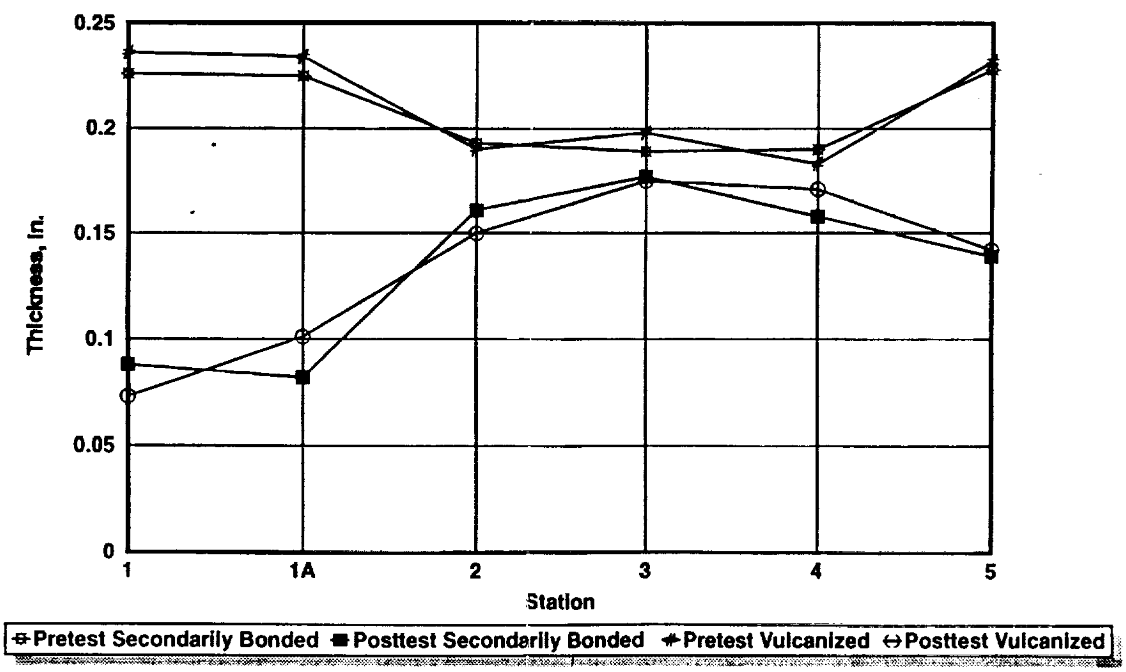
Measurement Station				
	2	3	4	5
3	0.190	0.185	0.195	0.230
1	0.195	0.190	0.195	0.228
5	0.195	0.190	0.192	0.228
7	0.192	0.190	0.193	0.230
1	0.195	0.191	0.186	0.225
3	0.190	0.193	0.185	0.225
0	0.192	0.184	0.195	0.228
8	0.192	0.190	0.180	0.225
0	0.195	0.190	0.190	0.233
8	0.193	0.190	0.192	0.231
5	0.193	0.189	0.190	0.228
3	0.002	0.003	0.005	0.003

ded Insulator Thickness, in.

Designation	Measurement Station					
	1	1A	2	3	4	5
IO736/1000695A*	0.095	0.075	0.160	0.197	0.149	0.128
K415/1000577F	0.066	0.094	0.165	0.175	0.160	0.144
K178/1000643F	0.088	0.083	0.169	0.187	0.154	0.126
W482/1000590F	0.083	0.085	0.172	0.148	0.155	0.133
IO667/1000712	0.096	0.083	0.156	0.160	0.178	0.140
K135/1000644	0.080	0.086	0.160	0.186	0.171	0.148
IO885/1000644	0.106	0.076	0.149	0.171	0.153	0.151
W483/1000605	0.090	0.070	0.154	0.190	0.140	0.140
K205	0.105	0.084	0.171	0.203	0.190	0.175
K150	0.100	0.092	0.170	0.199	0.154	0.148
Average	0.091	0.076	0.163	0.182	0.160	0.143
Standard deviation	0.012	0.007	0.008	0.018	0.015	0.014
Average/standard deviation	7.583	10.857	20.375	10.111	10.667	10.214

*Closure S/N/motor S/N

D. Posttest Secondarily Bonded Insulator Thickness, in.



F. Comparison of Average Insulator Thickness, Pretest and Posttest

93508-026JH

Figure 6.3-24. Vulcanized Insulator Performance Comparison with Secondary Bonded Insulator Performance

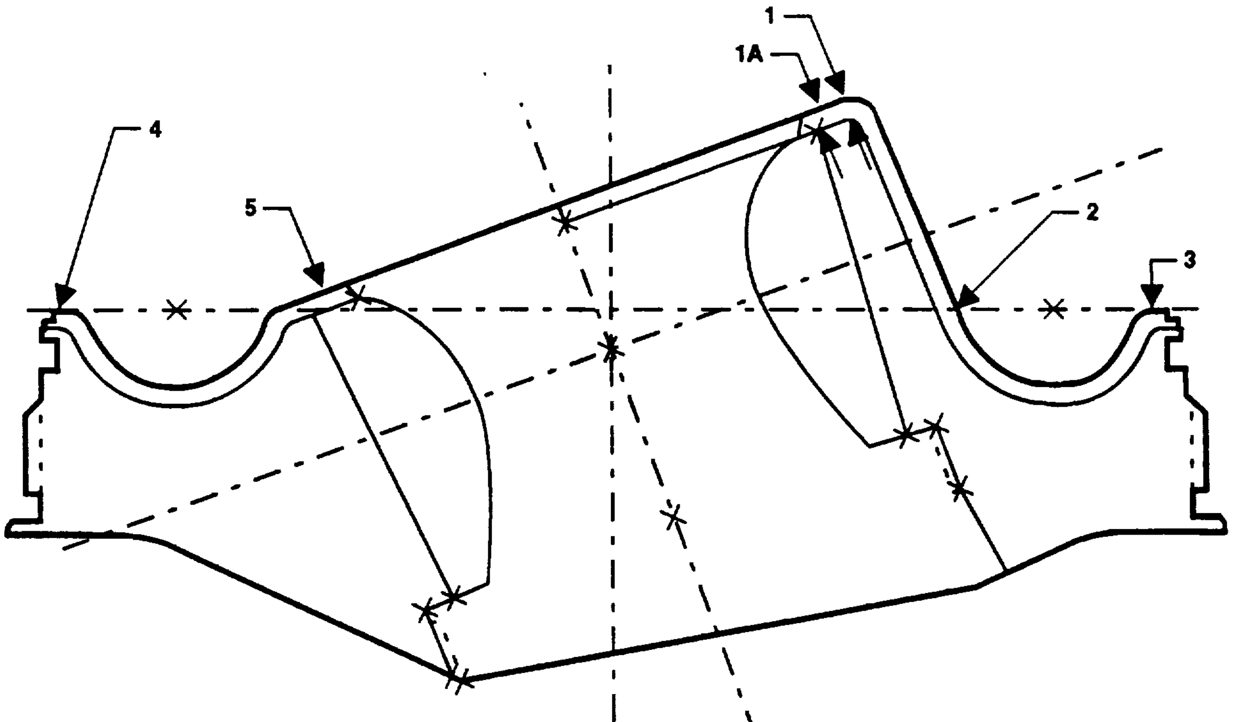


Figure 6.3-25. Aft Closure Insulator Thickness Measurements

The regions of the aft closure insulators subjected to the most severe environment are those defined as locations 1 and 1A (figure 6.3-25). This is due to the severe flow conditions (i.e., high gas flow velocity and high mass flow) as evidenced by visual posttest inspection and the posttest measurements from figure 6.3-24. Therefore, to assess the acceptability of incorporating the vulcanized insulator into the BSM flight hardware, a further assessment of this region was made.

Using the data from figure 6.3-24, a comparison of the 1 and 1A thicknesses for secondarily bonded insulation performance with vulcanized insulation shows that for these randomly chosen specimens the performance of the insulation is equivalent and, in addition, that both of the Delta Qualification 2 insulators meet the factor-of-safety requirement with conser:ative values of 1.33 and 1.38 for the hot and cold motors, respectively. These factors are calculated using the minimum mold design thickness of 0.220 in. and the average pretest vulcanized insulator thickness of 0.236 in. from figure 6.3-24(A). Using the actual maximum pretest thickness of 0.25 in. results in factors-of-safety of 1.39 and 1.43 for the hot and cold motors, respectively. These values are representative of the actual pre- and posttest vulcanized insulator conditions. Also, when compared to other fired units as shown in the table, the vulcanized insulator performance is within family and is considered to be acceptable to the insulated closure requirements of 10SPC-0067.

The Chemlok vulcanization bond gives a durable, high-strength bond unaffected by the amount of heat conducted through the insulation during the BSM firing. The insulator provided thermal protection to keep the bondline temperatures low enough to not degrade the Chemlok system even with thermal soak. Since the bond system did not degrade, there was no creation of bondline voids or unbonds. There is no posttest bond requirement. The insulation maintained the nozzle closure at temperatures low enough to ensure no degradation of the aluminum mechanical properties, which meets the requirements of paragraph 3.2.1.3.7 of Specification 10SPC-0067.

6.3.4 Conclusions. Based on the analyses above, the following conclusions are presented with respect to qualification of the vulcanized aft closure insulator and its incorporation into BSM flight hardware.

- The test data demonstrates the compliance of the vulcanized insulators on the two Delta Qualification motors with the requirement of the minimum safety factor of 1.25 defined in Specification 10SPC-0067 (minimum safety factor calculated to be 1.33).

- Analysis by similarity of the vulcanized insulators to the performance of secondarily bonded insulators shows that the performance of the vulcanized insulators is within and consistent with the database for post-fired secondarily bonded components

- Detailed examination of the posttest condition of the vulcanized insulators shows:
  - A significant amount of virgin material still in place after the test
  - An insulator/closure bondline that is still totally intact
  - An aluminum closure that shows the total absence of any heat or gas flow effects
  - Even ablation/erosion which indicates uniform material removal.

- The vulcanized insulated closure provides enhanced product integrity. Post-fire tap tests show that the entire bondline was intact. The secondarily bonded design had variable thickness bondlines and less than 100% bonded areas (although it still had positive margin-of-safety due to the low bond strength actaually required during motor operation). Peel test data documented in the Vulcanization Interim Test Report in Appendix L, Volume III, Book 2 show the vulcanization process yields increased strength over the EA 913NA secondarily bonded insulator method. Therefore, the margin-of-safety is increased, enhancing the product quality. Also, the vulcanized bondline is more resistant to high temperatures. In order to remove a secondarily bonded insulator during normal production, it is heated to 210°F and peeled from the closure. It has been demonstrated that a vulcanized insulator cannot be peeled from the closure at this temperature. Consistent, low thickness bondlines, higher peel strength, and more temperature resistant bonds have improved the closure bonding design.

- The vulcanized insulated aft closures met all of the success criteria with the exception of the 0.090-in. maximum erosion requirement. (See NCRs D14416 and D14417 in Volume II, Book 2, Appendix J.) All erosion margins of safety were positive and the vulcanized insulator design is acceptable for qualification and inclusion into BSM flight hardware.

6.3.5 Recommendations. Based on the demonstrated performance of the vulcanized insulator on the Delta-Qualification static tests, it is recommended that the vulcanized insulator be approved for incorporation into BSM flight hardware.

6.4 UNINSULATED IGNITER ADAPTER. The present design for the igniter adapter requires that a thin, rubber insulator be bonded to the igniter adapter to "protect" the stainless steel component from the motor environment. This is a labor-intensive effort and appears to provide little added value to the quality or operation of the BSM.

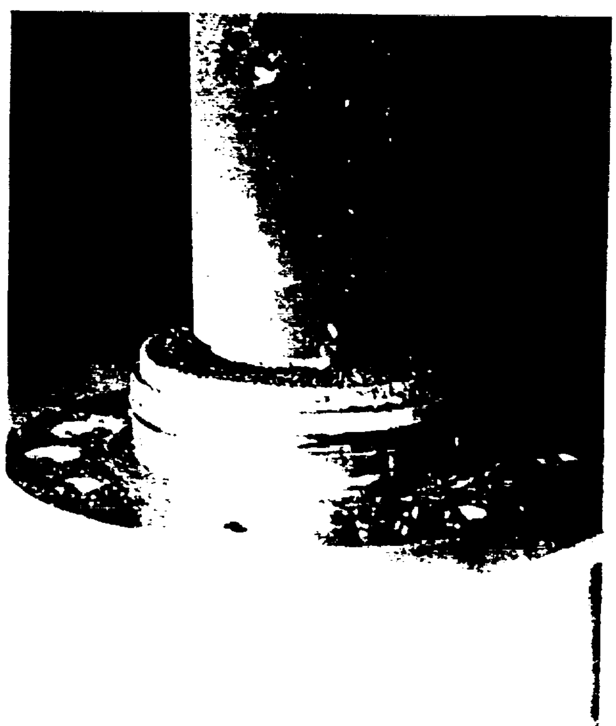
6.4.1 TQM Initiative Description. The insulated igniter adapter is located in the forward end of the BSM. This is a relatively stagnant flow regime in the motor and an area of low heat flux. Preliminary analyses (see Appendix G) showed (1) that an uninsulated igniter adapter would withstand the motor operating environment, and (2) that under the worse case scenario the "removal" of cadmium plating on the uninsulated igniter adapter during motor operation would create a less severe debris condition than that caused by the aluminum in the BSM propellant. The TQM initiative included in the Delta Qualification motors was the elimination of the igniter adapter insulator.

6.4.2 Success Criteria. The success criteria established for qualifying the uninsulated igniter adapter were: (1) absence of surface melting of the igniter adapter, and (2) lack of debris ejection either from the cadmium coating or from the igniter adapter material as determined from high speed motion pictures.

6.4.3 Test Results. The posttest visual examination showed that the igniter adapter aft face had minimal heat effects and no evidence of surface melting (figures 6.4-1, 6.4-2, 6.4-3 and 6.4-4) and nearly uniform color. The cadmium plating on the igniter adapters of both motors, when tested with iridite, showed that the cadmium coating was nearly uniformly present and did not exhibit any flaking of the coating. This was further confirmed by the absence of any debris being ejected by either motor based on the review of the high speed movie films.

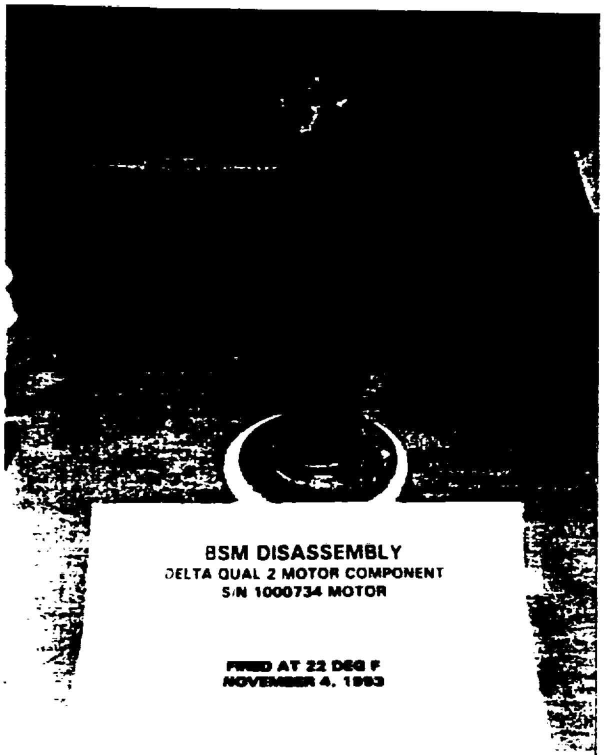
C20941-13

Figure 6.4-1. Motor S/N 1000738 (129.5°F) Uninsulated Igniter Assembly, Posttest View



C20941-14

Figure 6.4-2. Motor S/N 1000738 (129.5°F) Igniter Assembly, Posttest Closeup of Uninsulated Igniter Adapter



C20941-22

Figure 6.4-3. Motor S/N 100734 (22.2°F) Igniter Assembly, Posttest View

C20941-23

Figure 6.4-4. Motor S/N 1000734 (22.2°F) Igniter Assembly, Posttest Closeup of Uninsulated Igniter Adapter

The uniformity of the posttest cadmium coating indicates that if any of the coating is removed, it boils off and uniformly erodes rather than coming off in flakes.

6.4.4 Conclusions. The following conclusions are provided based on the posttest inspections of the uninsulated igniter adapters:

- The uninsulated igniter adapter does not melt or erode during the BSM operation or posttest soakout.
- The cadmium plating on the igniter adapter stainless steel surface does not flake during motor operation and does not create any identifiable debris.
- Deletion of the insulator on the igniter adapter does not adversely impact the integrity or operation of the BSM.
- Deletion of the insulator on the igniter adapter provides for enhanced BSM producibility.
- The uninsulated igniter adapter met all of the success criteria established for its qualification and inclusion into BSM flight hardware.

6.4.5 Recommendations. Based on compliance of the uninsulated igniter adapter with the success criteria established for its qualification and its potential for improving the BSM producibility without compromising the product quality, incorporation of the uninsulated igniter adapter into the BSM flight hardware is recommended.

6.5 DELETION OF RTV BEAD AT IGNITER CASE/ADAPTER INTERFACE. The present design requires the application of an RTV bead between the igniter adapter and the igniter adapter case. As with the igniter adapter insulator addressed in subsection 6.4, this is a labor-intensive operation which appears to provide no added value to the BSM.

6.5.1 TQM Initiative Description. The RTV bead between the igniter adapter and the igniter case, like the igniter adapter insulator, is located in a very benign flow field area of the BSM case interior.

Based on the same logic presented in subsection 6.4.1, the TQM initiative incorporated into the two Delta Qualification motors was the elimination of the RTV bead between the igniter adapter and the igniter case.

6.5.2 Success Criteria. In order for the deletion of the RTV bead to become qualified for BSM flight hardware, the igniter adapter and igniter case had to exhibit the absence of melting in the region where the RTV bead was eliminated.

6.5.3 Test Results. Visual inspection of the igniter adapter was completed following removal of the igniters from the two Delta Qualification motors.

The igniter case/igniter adapter interfaces showed no signs of degradation or melting where the RTV had been deleted from the design. There were no thermal effects on the thread relief area at the top of the igniter adapter threads. The pretest passivated surface finish of the machined 304L stainless steel igniter cases remained undisturbed after the firing for approximately 1¼ in. aft of this interface where the RTV was removed. The external surface of the igniter case aft of this 1¼ in. location that is sticking out into the combustion chamber and is completely uninsulated has never shown any signs of surface melting in over 50 previous disassembly inspections.

When the igniter case was removed from the igniter adapter, the threads of the igniter adapter showed no signs of melting or gas flow. The roll pins used to index the case and adapter were present and showed no signs of melting.

6.5.4 Conclusions. Based on the posttest visual inspection on the igniter adapter and the igniter case in the region where the RTV bead was removed, the following conclusions are provided:

- There was no melting of any material on the igniter adapter.
- There was no melting of any material on the igniter case.
- The elimination of the RTV bead between the igniter adapter and the igniter case does not impact the performance of the BSM.
- The elimination of the RTV bead between the igniter adapter and the igniter case enhances the BSM producibility.
- The elimination of the RTV bead between the igniter adapter and the igniter case met all of the success criteria established for its qualification and inclusion into BSM flight hardware.

6.5.5 Recommendations. Based on the results of the two Delta Qualification motor tests, which demonstrated compliance with the success criteria for qualifying the elimination of the RTV bead between the igniter adapter and igniter case, it is recommended that this TQM enhancement be approved for incorporation into BSM flight hardware.

6.6 DELETION OF LOCTITE FROM IGNITER RETAINER PLATE THREADS. As part of the final subassembly operation for the BSM igniter, Loctite is applied to the igniter retainer plate threads to ensure that the retainer plate will not inadvertently "unscrew" during motor handling, transportation, launch, or operation.

6.6.1 TQM Initiative Description. The BSM igniter assembly, shown in figure 6.6-1, requires that Loctite be applied to the threads of the retainer plate prior to mating of the retainer plate with the igniter grain subassembly. In order to fully understand the basis for this initiative, the following description is provided with respect to the method of igniter assembly.

The igniter retainer plate (reference figure 6.6-1) screws onto the igniter grain rod after the propellant grain is cast onto the rod. A phenolic insert is bonded into the bottom of the stainless steel igniter case and the propellant grain/rod with the installed retainer plate is then bonded into the igniter case. The bottom end of the grain rod is bonded into the phenolic centering insert which was previously bonded to the igniter case. This end of the igniter grain subassembly is then firmly centered and located into the igniter case.

As the igniter grain subassembly is installed into the igniter case, the retainer plate seats on a shoulder in the top end of the igniter case and prevents the igniter grain from further movement. When the igniter case subassembly is then installed onto the igniter adapter by screwing it in place, the retainer plate is captured between the aft face of the igniter adapter and the igniter case shoulder.

With one end of the igniter grain rod bonded into the phenolic insert and the other end captured in place, the igniter assembly components are fixed by design and cannot "unscrew"or move. Therefore, the use of Loctite on the retainer threads provides no added value to the BSM.

The TQM initiative incorporated into the two Delta Qualification motors was the elimination of the Loctite on the retainer plate threads.

6.6.2 Success Criteria. The igniter assembly must perform successfully after being subjected to all of the environments specified in paragraph 3.2.7.2.2 of 10SPC-0067. The environments are thermal cycling, shock and vibration testing and static firing at temperature.

Specifically, (1) the igniter rod must remain in place through the static test as verified by posttest visual inspection, (2) the igniter is to exhibit no anomalous gas flow paths associated with the elimination of the Loctite, and (3) the igniter is to ignite the BSM main grain within the parameter limits defined in 10SPC-0067 as verified by post-test ballistic analysis.

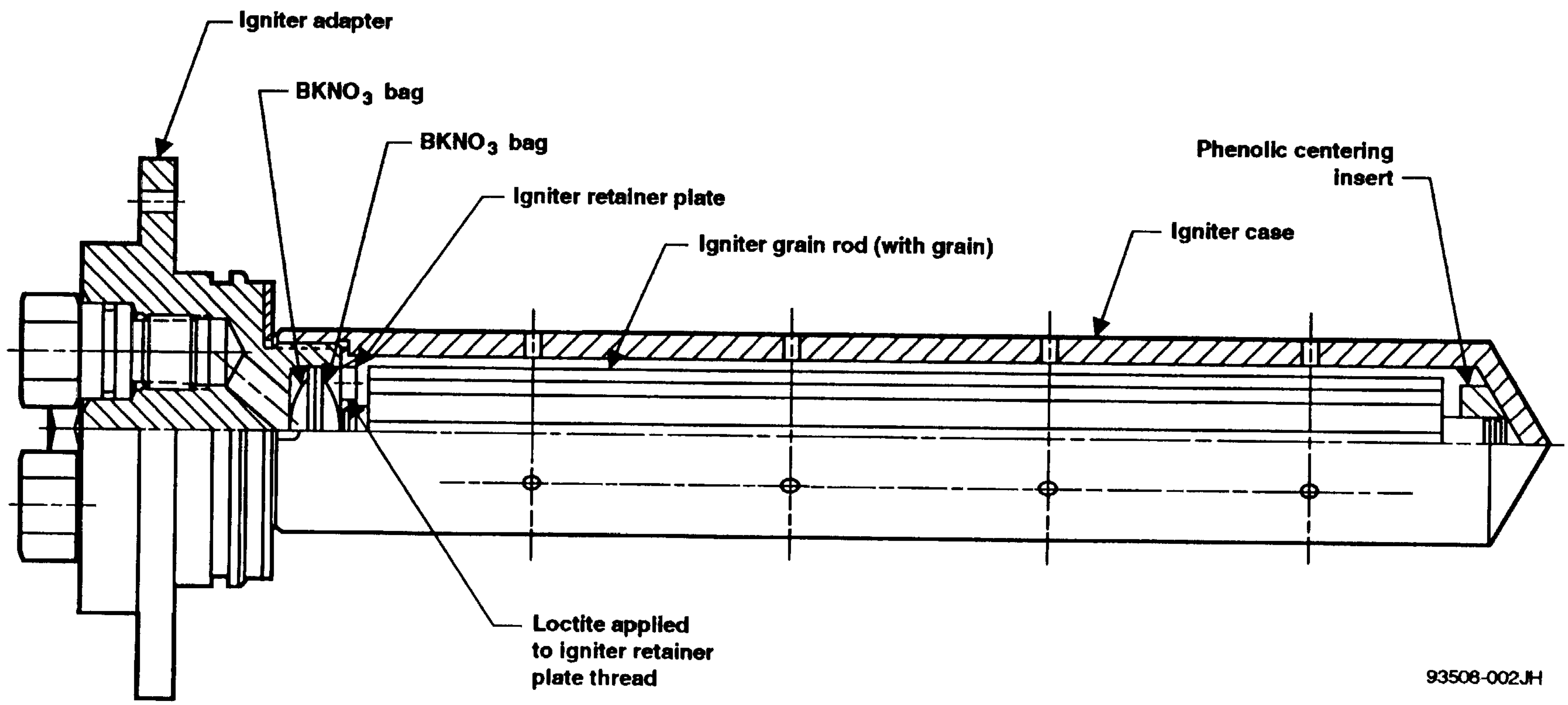


Figure 6.6-1. Igniter Assembly

6.6.3 Test Results. The following specific test results were obtained from the two Delta Qualification motors with respect to the elimination of Loctite application to the threads of the igniter retaining plate:

- Visual examination of the disassembled igniters showed that the igniter retainer plate/grain rod interface functioned normally with no signs of structural or functional damage.
- There were no signs of gas flow through the interface between the igniter retaining ring and the igniter rod or between the centering insert and the igniter case.
- Ballistic analysis of both motors verified performance compliance to the 10SPC-0067 requirements (reference Section 5).

6.6.4 Conclusions. Based on the test results as developed through posttest visual inspection and ballistic analysis of the two Delta Qualification motors, the following conclusions are provided:

- The removal of the Loctite from the threads of the igniter retaining plate did not impact the performance of the igniters in the two Delta Qualification motors.
- There was no evidence that removal of the Loctite compromised the integrity of the threaded interface between the igniter retainer plate and the igniter rod.
- The deletion of the Loctite from the igniter retainer plate threads met all of the success criteria established for its qualification and inclusion into BSM flight hardware.

6.6.5 Recommendations. Based on the successful testing of the igniter retaining plate/grain rod interface without the Loctite thread locking compound, it is recommended that this design change be approved for incorporation into flight hardware.

6.7 ADHESIVE EA-9394. The present design uses EA-913NA/L-3 epoxy adhesive for the following operations for BSM assembly:

- Nozzle closure throat insert bonding into the aluminum nozzle closure
- Igniter grain centering insert bonding into the igniter case
- Igniter grain rod into the igniter centering insert.

The production of the EA-913NA/L-3 epoxy adhesive is being discontinued by the manufacturer due to environmental considerations. In order to allow BSM production to continue, a replacement adhesive is required.

6.7.1 TQM Initiative Description. Several candidate replacement adhesives were identified by CSD and USBI for consideration as replacements for the EA-913NA/L-3 adhesive due to its near-term cessation of manufacturing by the supplier. Based on this list of candidates and the fact that the EA-9394 adhesive was qualified for other Shuttle applications, CSD was directed to baseline to the EA-9394 adhesive as the prime replacement for the EA-913NA/L-3 material.

Based on the results of a laboratory adhesive qualification test program (reference Appendix H in Volume III) conducted by CSD to determine by similarity if the EA-9394 adhesive performance was equal to or greater than that of the EA-913NA/L-3 adhesive and could be considered as a replacement bonding agent, the EA-9394 material was deemed acceptable for inclusion into the Delta Qualification motors as the replacement for the EA-913NA adhesive.

The EA-9394 epoxy was used in the motor assemblies to replace the presently used EA-913NA/L-3 epoxy adhesive for the three component bonding operations identified in subsection 6.7.

Preliminary acceptance of the EA-9394 adhesive was accomplished using an unloaded motor with the standard ATJ throat and igniter components bonded in place with the EA-9394 adhesive. This inert motor was then subjected to all of the Delta Qualification shock and vibration environments at MSFC. Posttest examination of this motor at CSD showed that the adhesive was not damaged by the shock and vibration environments.

Based on these test results, the EA-9394 adhesive was judged acceptable for inclusion in the Delta Qualification motors.

Inclusion of the EA-9394 adhesive in the two Delta Qualification motors which would be subjected to environmental and static tests would provide the final qualification for the EA-9394 adhesive.

The TQM initiative incorporated into the two Delta Qualification motors was the replacement of the EA-913NA adhesive with the EA-9394 adhesive for the three bonding operations identified in subsection 6.7.

6.7.2 Success Criteria. Per Test Plan CSD-5597-93-1, the EA-9394 adhesive success criterion was: "Demonstrate ability to retain Nozzle Throat and Igniter components in place during static test such that their performance is unaffected. Pre and post-test visual examinations will verify throat performance. Pretest x-ray and post-test sectioning will verify Igniter component joint performances."

6.7.3 Test Results. The nozzle assemblies were removed from the motor cases for examination. The gap between the nozzle exit cones and the aft end of the nozzle throat inserts was maintained, which shows that the adhesive held the throat insert in place on each motor during operation and heat soak. The posttest throat alcohol-wipe test showed no cracks, which is also an indication that the throat inserts did not move down the tapered nozzle closure containment interface with the corresponding increase in compressive stresses that could cause compressive hoop stress failure. The sectioning of the nozzle closures resulted in two halves for each closure with the nozzle throats maintained in place. Sectioning of closures with the EA-913NA/L-3 adhesive sometimes results in cutting blade induced loads that cause the inserts to move due to the heat soak weakened adhesive bond. The conclusion can therefore be drawn that the EA-9394 adhesive provides a stronger bond and that it is less susceptible to heat soak degradation.

The igniter assemblies were pretest inspected by x-ray to ensure that all components were present and in their proper positions. Both igniter assemblies successfully passed this inspection. The posttest inspection showed no external anomalies relative to the bonding of the rod/centering insert/igniter case interfaces. There were no indications of uneven burning, erosion, or gas flow that could be attributable to unbonded components after environmental and static firing. The main purpose of these bondlines is to hold the components in place prior to firing; there are no structural bonds.

6.7.4 Conclusions. Based on the test results of the laboratory adhesive qualification test program (reference Appendix H) and the test results from the Delta Qualification motors, the following conclusions are provided:

- The EA-9394 adhesive is equivalent to or superior to the presently used EA-913NA/L-3 adhesive for the applications addressed herein for BSM.
- The EA-9394 adhesive has pot life and viscosity characteristics compatible with BSM producibility requirements.
- The EA-9394 met all of the success criteria established for its qualification and inclusion into BSM flight hardware.

6.7.5 Recommendations. Based on the successful testing of the two Delta Qualification motors and the performance of the EA-9394 adhesive, it is recommended that, for the three bonding operations identified in subsection 6.7, the EA-9394 adhesive be approved for incorporation into flight hardware.

6.8 ISOSTATIC ATJ THROAT MATERIAL. The present ATJ material being used in the BSM through lot ABA is no longer available from the manufacturer. Therefore, a replacement graphite material is required for the BSM.

CSD identified two new graphite materials that are readily available, in use at CSD, and could be easily qualified for BSM. These two materials were Stackpole's 2020 graphite and Union Carbide's iso-static molded ATJ.

Both materials have been characterized to some extent by CSD. The Stackpole material has been used in our ballistic batch check motors at CSD and the Union Carbide material is used by CSD in our Titan staging motors, which is an application similar to that for BSM. The Union Carbide material has also undergone extensive characterization at Southern Research Institute (SRI) in support of the ATTACMs program.

6.8.1 TQM Initiative Description. Based on the available data, associated analyses that verified the material acceptability for use on BSM (see Appendix I), and the use of the material on Titan and ATTACMs, the Union Carbide material was selected as the candidate replacement material for the original ATJ.

Each of the Delta Qualification 2 motors incorporated a throat insert fabricated from the iso-static molded ATJ bulk graphite. These throat inserts were bonded in place with the new epoxy adhesive EA9394 (see subsection 6.7).

6.8.2 Success Criteria. Paragraph 3.2.1.2.3.1, page 20 of 10SPC-0067 requires the following: "The nozzle shall be designed to preclude the generation of debris, and to minimize expansion of the gaseous and particulate plume at EWAT and during thrust tailoff. The nozzle shall be designed to withstand all operational loads as defined herein and to withstand water impact loads to the extent that no debris is released."

The success criterion, as defined in Test Plan CSD-5597-93-1, is: "Demonstrate ability to withstand environmental and static test environments as evidenced by maintaining structural integrity (no cracks) and allowing loaded motor to meet program ballistic requirements."

6.8.3 Test Results. The nozzles and assemblies were subjected to the USB-specified environmental tests prior to the static firing tests (see Section 4).

Visual examination of the postfired inserts showed that the inserts performed normally (compared to present slurry molded ATJ bulk graphite throat inserts). The throat inserts were intact with no debris generated. The exposed surfaces exhibited uniform erosion and remained in their original position relative to the nozzle closure. The gap at the aft end interface between the insert and the exit cone did not change during firing and postfire heat soak.

After the nozzle closures were removed from the motors, an alcohol wipe inspection was performed on each insert and no indications of cracks were noted (see figure 6.8-1). The ballistic performance of the motors presented in Section 5 shows that the throat insert performance was acceptable and allowed all 10SPC-0067 specification ballistic parameters to be achieved.

6.8.4 Conclusions

- The iso-static ATJ material performance is equivalent to the present ATJ material.
- The iso-static ATJ material and the EA-9394 adhesive (see subsection 6.7) provide a compatible bonding system that readily withstands the imposed environmental and motor operation conditions.
- The iso-static ATJ material met all of the success criteria established for its qualification and inclusion into BSM flight hardware.

6.8.5 Recommendations. Based on the demonstrated performance of the iso-static ATJ throat inserts and the material's compliance with the success criteria established for its qualification, incorporation of the iso-static molded ATJ material into BSM flight hardware is recommended.

C-2.

UNITED TECHNOLOGIES CHEMICAL SYSTEMS

REQUEST FOR INSPECTION NO. [illegible]

Part Name	Part No.	Need Date
BSM Nozzle Assy (Fired)	812003	11/11/93

Quantity	Material Location	WOR No.	Requestor	Date
2	020	5597-986-0000	L. O. Murphy	11/4/93

Reason for request	Org. No	Ext
Verify fired hardware performance	1030	4403

Char No	Inspection Task	Inspection Results	Inspector Date
	Perform alcohol wipe test on two fired BSM Nozzle Assemblies S/N 1000734 S/N 1000738 Per WI 60.12.9-420	NO INDICATIONS NOTED ON 2-EACH 1000734 1000738	[illegible] CS 11/11/93

Manhours Expended	Inspection Supervision	Date
4.5	[illegible] J Thompson	11/11/93

CSD 1413 [illegible]

Figure 6.8-1. QC Report on Postfired Isostatic ATJ Inserts

Section 7
CONCLUSIONS AND RECOMMENDATIONS

The forward and aft BSM motors addressed in this report had the following enhancements incorporated into their configurations:

- Vulcanized-in-place nozzle aft closure insulation
- New iso-static ATJ bulk graphite throat insert material
- Adhesive EA-9394 for bonding the nozzle throat, igniter grain rod/centering insert/igniter case
- Deletion of the igniter adapter insulator ring
- Deletion of the igniter adapter/igniter case interface RTV
- Deletion of the Loctite from igniter retainer plate threads.

It is the conclusion of this report that all of the enhancements herein tested are qualified to be incorporated into flight hardware for the Booster Separation Motor.

Based on this conclusion and the recommendations associated with each of the enhancements as presented in subsections 6.3 through 6.8 of this report, it is recommended that all of the enhancements incorporated into these test motors be approved for incorporation into the manufacturing of flight BSMs for the Space Shuttle program.

Although all of the enhancements need not be included at the same time, the program should adhere to the following general guidelines:

- Enhancement incorporation should be scheduled in a manner compatible with the BSM production schedule
- Enhancements must be incorporated at the beginning of the selected production lot(s); i.e., all motors in the production lot must contain the approved enhancement(s)
- The lot(s) for which enhancements are first incorporated should be selected based on hardware availability and the enhancement incorporation at the selected lot(s) should provide cost benefit to the customer.

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REFERENCES

1. Report CSD 5596-87-2, "BSM O-Ring Referee Tests, No O-Ring Configuration."

2. Report CSD 5596-87-3, "BSM O-Ring Referee Tests, No RTV."

3. Report CSD 5596-87-7, "BSM Nozzle Closure Insulation Edge Unbond Referee Test."

4. Report CSD 5596-87-6, "BSM O-Ring Performance Evaluation."

5. Report CSD 5596-88-1, "BSM Nozzle Closure Insulation Bond Validation Static Motor Test."

6. Report CSD 5596-88-2, "BSM Design Acceptance Verification Static Motor Test."

7. Report CSD TR 5596-89-1000, Booster Separation Motor 8-Year Service-Life Demonstration."

8. Report CSD 5596-88-3, "Booster Separation Motor Delta Qualification Test Report."